THE EMERGENCE OF ORGANIZATIONS AND MARKETS

John F. Padgett
Walter W. Powell
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overview of theory ...
(chapter 1)
Black hole of genesis

• At its foundational core, current social science cannot explain novelty, especially emergence of new types of actors:
  -- persons, organizations, states and markets

Because methodological individualism cannot derive its own axioms

• We need a theory of transformational flows, out of which objects and behaviors emerge
Biochemistry as inspiration

• Chemistry does not contain all the answers, but it points in the right direction

• Origins of life
• Social structure as vortex
• Example of the human body:

  no atom in your nose was there two years ago
Components of the theory

I. Autocatalysis
   -- the network version of Darwin

II. Multiple networks
   -- over time, in resource and biographical feedback

III. Network-folding mechanisms of organizational genesis
     -- the network version of Mendel
I. Autocatalysis: Chemical

• From origins of life literature (Manfred Eigen),

Autocatalysis = chemical definition of Life:
“Set of nodes and transformations in which nodes are constructed by transformations among nodes in the set.”

• “Nodes” can be molecules, products, people, or symbols/words, as long as transformed through interaction
Autocatalysis: Social

• Padgett and Powell mantra:
  *In the short run, actors make relations.*
  *In the long run, relations make actors.*

• “Actors” are composites of production rules, relational protocols, and linguistic addresses.

• Each of these reproduce and recombine as they flow through people and organizations.
3 types of Autocatalysis

• Production autocatalysis
  -- products flow in trade through skills in cells
  -- skills reproduce and die
• Biographical autocatalysis
  -- skills flow through teaching among cells
  -- cells reproduce and die
• Linguistic autocatalysis
  -- symbols flow through addresses (names) of cells, thereby channeling flows
  -- symbols and addresses reproduce and die
Economic Production as Chemistry

Figure 3. Representative 5-Skill Hypercycles at Equilibrium: Target Reproduction

Fixed-Rich Environment; Selective Search:

Fixed-Rich Environment; Random Search:

# Hypercycles= 7

# Hypercycles= 39
Agent-based modeling findings

Autocatalysis more likely and more complex when:

• Spatial (or network), not random, interaction
  -- mosaic of heterogeneous learning dyads
• Altrustic, not selfish, reproduction
  -- because of direct repair
• Stigmergy
  -- because of indirect repair
• Multiple networks (i.e., domain differentiation)
  an automatic corollary of autocatalysis
II. Multiple Networks

• Autocatalysis is the emergence of life, but that is not speciation, which is the tipping of one form of life into another

• To get speciation, need multiple autocatalytic networks that interlock and tip each other
  -- multiple networks essential for evolution
  -- otherwise “equilibrium” which is dead
Figure 1. Multiple-network ensemble Renaissance Florence

ECONOMIC:
Guild 2

Guild 1

KINSHIP:

Neighborhood 1

Neighborhood 2

POLITICAL:

Social Class 1

Social Class 2

Social Class 2

Social Class 1

Note: (a) Solid lines are constiutive ties. Dotted lines are relational social exchanges. Oblongs are formal organizations (families and firms.)
(b) People in multiple roles are verticle lines connecting corresponding dots in the domains of activity in which people are active. (Only two are shown for illustration.)
Innovation vs. Invention

• **Organizational Innovation** = cross-domain recombination of networks (vertical Δ in fig)
  -- transposing production or relational practices across domains

• **Organizational Invention** = spillover into tipping domains themselves (horiz. Δ in fig)
  -- making new industries or fields
III. Network-folding mechanisms of Organizational Genesis

P&P documented eight network-folding mechanisms that created new organizational forms:

1. Transposition and Refunctionality
   -- Renaissance Florentine partnership
   -- biotechnology in contemporary U.S.

2. Incorporation and Detachment
   -- medieval international finance

3. Anchoring Diversity
   -- regional clusters in U.S. life sciences

4. Migration and Homology
   -- stock market in early-modern Netherlands
Network-folding mechanisms of Organizational Genesis (cont.)

5. Conflict Displacement and Dual Inclusion
   -- Bismarck in 19th-century Germany

6. Purge and Mass Mobilization
   -- Stalin, Gorbachev, and Yeltsin in USSR
   -- Mao in Cultural Revolution

7. Privatization and Business Groups
   -- post-Communist Hungary

8. Robust Action and Multivocality
   -- Cosimo de’ Medici in Florence
   -- Deng Xiaoping in China
Florence example of Transp. & Refunct.

**Transposition:**
- CIOMPI REVOLT
- Politics
- Economy
- City council
- Economic mobilization
- Political co-optation
- International merchants
- Domestic bankers

**Refunctionality:**
- Politics
- Ex-city councilors
- Republican merchants
- International merchants
- Domestic bankers
- Partnership systems
Biotech example of Transp. & Refunct.

Transposition:

Finance

Science

Refuunctionality:

Finance

Science
Conclusions

Q: Where do actors come from?

Autocatalytic concatenations of transformation flows
-- of skills and of relations.

Q: Where does novelty come from?

Novelty (innovation) = transposition across multiple networks
-- network overlays (social embeddedness) create
“topology of the possible”

Speciation (invention) = cascades into co-evolution
-- org novelties that tip the networks that select them
Chapter 3:
ECONOMIC PRODUCTION AS CHEMISTRY II

John F. Padgett,
Peter McMahan,
and Xing Zhong
The Emergence of Organizations and Markets

John F. Padgett • Walter W. Powell
Overview

Four sequential Padgett papers on autocatalysis:


(all on http://home.uchicago.edu/~jpadgett)
Economic Motivation: Firms as Life

“The production and distribution of goods by firms are only half of what is accomplished in markets. Firms also are produced and transformed through goods passing through them. This transformation is not just a matter of profits. Skills and the core competencies that define firms are developed and maintained through ‘learning by doing’ and other learning processes that are triggered by exchange among firms.”
Autocatalysis

The chemical definition of life is autocatalysis:
-- “a set of nodes (chemicals, but also skills and people) whose interaction reconstructs the nodes in the set”

Network implications:
-- not networks of resource flow, but networks of transformations \{i \rightarrow j\}, like chemical reactions
-- topologically, cycles of transformations are the key: nodes in core need transformation arrows coming in
-- exhibits repair: if subset of nodes is destroyed, other nodes in interaction will reconstruct them (given food)
3 types of Autocatalysis

1. **Production autocatalysis** (in ICC & chapter 3):
   skills reproduce through product transformation and exchange

2. **Biographical autocatalysis** (in chapter 4):
   people reproduce through teaching of skills and relational protocols

3. **Linguistic autocatalysis** (in chapter 4):
   symbols reproduce through conversation
Production Autocatalysis: Overview

Extension of Eigen and Schuster’s hypercycle model:

Elements of minimalist model:
- products \{1, 2, 3, ..., n\}
- rules \{(1 \rightarrow 2), (2 \rightarrow 3), ...
- exchange: spatial vs non-spatial
  (if spatial, then rules contained in bins)
- 2 chemistries: SOLO H (= hypercycle) and ALL

Bins (\sim firms) contain rules and pass products to each other, transforming them as they go.

Rules reproduce or die off, depending on success in transforming products. (\sim Darwin)
Production Autocatalysis: Model Output

Figure 3. Representative 5-Skill Hypercycles at Equilibrium: Target Reproduction

Fixed-Rich Environment; Selective Search:

Fixed-Rich Environment; Random Search:

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Core model of production: random baseline

1. There are three components in the model: rules (‘skills’), balls (‘products’), and bins (‘firms’).

2. Balls/products are indexed by $i = 1, 2, 3, ..., n$. The parameter $n$ characterizes the relative ‘complexity’ of the particular rule set under investigation.

3. Rules/skills transform balls/products into other balls/products, according to one of two families of chemistries: SOLO H and ALL.
   -- SOLO H is the linear cycle of Eigen and Schuster:
   $$\{(1 \rightarrow 2), (2 \rightarrow 3), (3 \rightarrow 4), ..., (n \rightarrow 1)\}$$
   -- ALL is all transformations, except identity:
   $$\{(1 \rightarrow 2), (2 \rightarrow 1), (2 \rightarrow 3), (3 \rightarrow 2), ..., (n \rightarrow n-1), (n-1 \rightarrow n)\}$$
Core model of production: random baseline (cont.)

4. Rules/skills are contained in bins/firms. At the beginning of each simulation, skills are just randomly distributed across available firms, without any logic. The number of firms initially is large.

5. Bins/firms are arrayed on a spatial grid, with wrap-around boundaries. Each firm has eight possible nearest-neighbor trading partners – i.e., Moore neighbors.

6. At each asynchronous iteration of the model, a random rule is chosen ‘looking for action.’ The firm containing that rule reaches into the input environment (modeled as an urn) and draws an input ball. If the input ball selected is compatible with that rule, then the ball is transformed according to that rule. (For example, if a firm possessed an activated $1 \rightarrow 2$ rule, and it drew a 1 as input from the urn environment, then it would transform the input 1 into the output 2.) If the ball selected could not be processed by the activated rule, then input ball passes through the firm into the output environment (also modeled as an urn) unchanged.
Core model of production: random baseline (cont.)

7. Products successfully transformed within the firm are passed randomly to one of the firm’s eight possible trading partners. If that trading partner possesses a compatible skill, then it transforms the product further, and passes that along in a random direction. (For example, if the second firm possessed a ‘2→3’, then after receiving the output ‘2’ from the first firm, it would transform the ‘2’ into a ‘3’, and then pass that on to a third firm or possibly back to the first.) In this way, transformed products pass through sequences or chains of skills.

8. Bins/firms continue passing around transformed products among themselves until the product lands on a firm that does not possess a compatible skill to transform it further. At that point the product is ejected into the output environment/urn. And a new input ball is selected to begin the iterative process all over again.
Core model of production: Summary

• Overall image like popcorn, chaotically popping in vat – no logic or purpose.

• What is necessary for such a random system to develop self-organization or coherence?

• Answer: feedback.
   In particular: learning and forgetting.
Core model of Learning

1. ‘Learning by doing’ is modeled in chemical fashion as follows: If one skill transforms a product and passes it on to a second skill that transforms it further, then a skill is reproduced. We call such a sequence a ‘successful transaction,’ since a product was made that was used. Which of the two skills is reproduced in a successful transaction – sender or receiver – is an experimental variation within the model.

2. ‘Forgetting’ is modeled in chemical fashion as follows: Whenever one skill reproduces anywhere in the system, another skill, randomly chosen from the overall population of skills, is killed off. The total population volume of skills in the population thus is held constant.

3. Once a firm loses all its skills, it ‘goes bankrupt’ or ‘dies’, never to recover any skills.
Core model of Learning: Summary

• “Learning by firms” =
  “Reproduction of its rules”:
  a ‘germ’s eye view’ of learning.

• Together learning and forgetting impose competitive selection on rules:
  -- those that reproduce survive
  -- those that do not go extinct.
Dependent variables

• Probability of autocatalytic network emergence and survival:
  -- likelihood of pretty pictures, like above

• Structure of networks that emerge (if they emerge):
  -- Population/market size of surviving firms
  -- Rule complexity (number of surviving types of rules)
  -- Subsystem complexity (for all, number of networks)
  -- Number of Parasites or free-rider rules
Independent variables (experimental variations)

- Type of chemistry: SOLO H versus ALL
- Complexity of chemistry: n
- Spatial versus non-spatial
- Types of reproduction:
  - Target (‘altruistic’) versus Source (‘selfish’)
- Resource environments:
  - fixed rich, fixed poor, or stigmergy
- Search intelligence: random or selective
Target versus Source Reproduction

• Chemistry version of selfish versus altruistic.
• Given a successful transaction,
  -- Source ("selfish") reproduction is when initiator of transaction rewarded.
    -- like a teacher.
  -- Target ("altruistic") reproduction is when recipient of transaction rewarded.
    -- like a student.
Variation in Resource environments

• “Fixed rich environment”:  
  -- input urn contains all types of product.

• “Fixed poor environment”:  
  -- input urn contains only one type of product

• “Stigmergy” or endogenous environment:  
  -- output products normally put into output urn are inserted into input urn instead.
  -- thus over time, autocatalytic production constructs its own input resource environ.
Variation in Search intelligence

- “Intelligence of an atom”: 
  -- initiating rule reached into input urn and draws a product/ball randomly.

- “Intelligence of a cow”: 
  -- initiating rule reaches into input urn and draws the product/ball it is looking for.
Results: Emergence rates for SOLO H

Survival: SOLO H chemistry

% hypercycles alive (out of 30 runs)

Target: rich, Target: poor, Source: rich, Source: poor, Stigmergy: rich, Stigmergy: poor, Nonspatial: rich
Effect #1: Spatial vs Non-spatial

• Non-spatial faces “complexity barrier” at 5:
  (shown by Eigen and Schuster)
  for \( \leq 4 \) rules, hypercycles always emerge:
    low-level life easy to self-organize
  for \( > 5 \) rules, hypercycles never emerge:
    complex life hard to self-organize

• But spatial can break complexity barrier
  -- this why real life is embodied
Reasons for Spatial effect

• Space “breaks symmetry” of everyone-to-everyone interaction, -- thereby enabling heterogeneity in local histories.

• This makes Path-dependency: histories of diverse localized interactions become inscribed into rule compositions of firms -- rule composition becomes primitive memory of past successful transactions.

• Hence co-evolution of complementarity among neighbors.

• This why “firms” (restrictions on interaction) exist. -- Space induces heterogeneity and memory.
Reason for Spatial Superiority (cont.)

• Big finding:

  Heterogeneous learning and localized memory
  is chemistry reason for embodiment.
Effect #2: Target superior to Source

• Target (“altruistic”) reproduction always superior, -- especially in rich environments.

• Source (“selfish”) vulnerable to self-destructive feedback/growth, like cancer:
  -- initiator of successful transaction →
  initiator reproduces,
  & random rule dies → prob. of high-frequency initiator initiating again rises.
  -- eventually initiator kills off recipient rules, on whose existence he depends.
Reason for Target’s superiority

- In contrast, target repairs:
  -- initiator of successful transaction → recipient reproduces,
  & random rule dies → prob. of high-frequency initiator initiating again drops.
  -- High-volume firms reach into low-volume firms to build them back.
  -- smoothing out “peaks and valleys” in hypercycles, to benefit of all
Reason for Target’s superiority (cont.)

• Big finding:

  Repair is the chemistry explanation for evolution of altruism.
Effect #3: Stigmergy

• Adding endogenous environment to selfish Source reproduction can sometimes alleviate its self-destructive woes.

• Like “stigmergy” in social insects: feedback between social and physical.

• This works because of indirect repair:
  -- initiator builds up resources in shared environment (urn) that recipient can use, and depletes his own.
Effect #4: Search intelligence

• “Intelligence of atom” versus “intelligence of cow”:
  -- Big difference in speed to equilibrium,
  -- But no difference in probability of reaching equilibrium or in properties of equilibrium.

• Humans can affect speed of evolution, but do not abolish laws of evolution.
Moving on to ALL chemistry...
(chapter 3 in Padgett/Powell book)

• Do hypercycle (SOLO H) results generalize?
  -- What about arbitrary chemistries, not ones constrained to loops?

• In particular, ALL permits multiple cycles, intertwined in each other.
  -- Can multiple technological networks emerge, in symbiosis?
Survival of autocatalytic networks: ALL chemistry

% autocatalytic networks alive (out of 30 runs)

2-ball 3-ball 4-ball 5-ball 6-ball 7-ball 8-ball 9-ball

Target:rich  Target:poor  Source:rich  Source:poor
Stigmergy:rich  Stigmergy:poor  Nonspatial:rich
Survival of autocatalytic networks under ALL

• Again superiority of spatial to non-spatial is clear.
• But most of this is low-level 2-rule hypercycles -- like reciprocal \{ (3 \rightarrow 6), (6 \rightarrow 3) \}.

• What we really are interested in is emergence of more interesting forms of life than that, -- which can self-organize on top of such reciprocity foundations.
Survival of autocatalytic networks: ALL chemistry, 3+ cycles
SOLO-H results carry over to ALL

- Rank order of survival rates for hypercycles of 3+ complexity same for ALL as for SOLO H:
  -- Target ("altruistic") in rich environment is best by far.
  -- Stigmergy (under either target or source) is second best.
  -- Target under poor environment is next.
  -- Source ("selfish") without stigmergy is worst.

- Only difference is number of rules ("complexity") in starting chemistry does not matter.
  -- ALL finds subset of rules that can work.
What about Structural properties?

- In following graphs, I will show equilibrium
  -- number of firms
  -- number of distinct rules ("rule complexity")
  -- number of distinct production networks ("subsystem complexity")
  -- number of parasite or free-rider rules.

- Main news under ALL is subsystem complexity.
Number of cells/firms

Population: ALL chemistry

# cells alive (average if alive)

Target:rich  Target:poor  Source:rich
Source:poor  Stigmergy:rich  Stigmergy:poor
Number of production rules

Rule complexity: ALL chemistry

# distinct rules alive (average if alive)

Target:rich
Target:poor
Source:rich
Source:poor
Stigmergy:rich
Stigmergy:poor
Nonspatial
Number of production networks

Subsystem complexity: ALL chemistry

Target:rich  Target:poor  Source:rich  Source:poor  Stigmergy:rich  Stigmergy:poor

# distinct cycles (average if alive)
Subsystem Differentiation

• Main reason I call “subsystem complexity” the main new conclusion to come out of ALL is the automatic emergence of multiple networks or “functional differentiation,” as sociologists call it.
  -- The first model I know to derive this.

• By this I mean in same network, for example:
  -- {((1→2), (2→3), (3→1)}, and
  -- {((8→2), (2→3), (3→5), (5→8)}. 
Subsystem Differentiation (cont.)

- Target (rich env.) generated on average 4-6 interlinked networks or subsystems.
- Stigmergy (source or target) generated on average 2 interlinked networks or subsystems.
- Source (“selfish”) did not really differentiate into subsystems, usually finding only a single pair of reciprocating rules, laid out like checkerboard.
- Dynamics of multiple networks very important in our empirical work on genesis of org novelty in history.
Conclusion

• This talk has covered only my baseline model of Production Autocatalysis.

• In chapter 4, I also outline two extensions:
  -- “Linguistic autocatalysis” where symbols (primitive language) are introduced to allow exchange networks to develop endogenously, beyond just spatial.
  -- “Biographical autocatalysis” where teaching of rules is introduced to allow the emergence of biographies and lineages/families.
  -- consult chapter 4 for explanation of those.

• Bottom line: The Economy is one form of Life.
Chapter 5:
THE EMERGENCE OF
CORPORATE MERCHANT-BANKS
IN DUGENTO TUSCANY

John F. Padgett
The Emergence of Organizations and Markets
Commercial revolution of the 1200s
(Lopez, Sapori, de Roover)

-- rise of sedentary merchants
  -- before, in fairs, merchants moved with goods
  -- branch offices (*filiali*), connected through writing
  -- central account book (*ragione sociale*)
-- legal and social continuity through time
  -- the medieval *corpo*-ration (*società*):
    obligations transcend businessman himself
  -- often rooted in patrilineage
-- examples: Bardi, Peruzzi, Scali, Bonsignori merchant-banks

I studied letters in papal registers and writs in English Liberate rolls.
New organizational form = Medieval corporation

**Before:** Champagne fairs
-- seasonal migration of textiles and merchants
-- money-changers to settle coin payments at end of fair

**After:** Italian sedentary merchants
-- geographically dispersed offices with (often related) partners as branch managers
-- moving goods, not merchants:
   letters/orders for textiles, and
   bills of exchange for money
-- *corpo* = startup capital = the body of “corporation”
Cultural foundations: the medieval meanings of “corporation”

Business becomes body (corpo), like family and church
  -- no longer just individual merchants and their contracts

Multiple medieval meanings of corpo:
  -- partners’ start-up capital, but with
  -- legal continuity through time,
    like church as body of Christ
  -- unlimited liability, through patrimony of family

Practical implication for operations:
  -- single centralized account book (ragione sociale)
    -- possibility of written rolling credit
Mechanism of Organizational Invention: Incorporation and Detachment

In overview:

I. Incorporation = Market into Church
   -- Pope coopted Tuscan merchants from Champagne fairs into papal administration,
   -- in order to collect military levies for Italian crusades.

II. Detachment = from Church to England and new trade
   -- Tuscan merchants later leave Pope to work for King of England and to trade and process wool.

Thus international finance emerged out of organizational hybridization of merchant fair with Church.
Consequences of Incorporation

Organizational consequences of continued old roots in fairs:

-- much liquid money
-- techniques: contracts, partnership, deposit accounting

Organizational consequences of new incorporation into Church:

-- merchants become one wing of crusade militia,
  in “body of Christ procession” to heaven
-- sedentary geographical imprinting:
  merchants become banking adjuncts of bishops,
  in order to get their loans back through church admin.
-- organizational concepts of *corpo* and office
-- business orders now in written letters,
  like papal bulls themselves
Organizational Birth through Italian crusades

Military

Religion

Crusader army

Church

WAR with Holy Roman Emperor

Detachment

Incorporation

Economy

Tuscan merchant-banks

Champagne fairs

catalysis: companies into families

Kinship

patrician families

new-man families
Organizational Spillover through Detachment

So much for Pope’s creation of temporary organizational novelty, now how did that novelty spill over into transforming international finance and trade?

Answer best explained through sequence diagram:

-- first transposition to King of England, which triggered
-- a second organizational novelty: English customs
-- allowing Tuscans to hijack English wool from Flanders
to build Florentine textile industry
Autocatalytic Spillover

- Charles of Anjou
  - mercenary
- Pope
  - old levies
  - fifths
  - crusades
    - levy
  - m-b
- Tuscan nobles
  - patrilineage
  - loans
    - 2
- Tuscan merchants
  - m-b
  - recruitment
    - loans
  - wool
    - textiles
  - textiles
    - Champagne fairs
  - textiles
    - Customers
      - (merchants + wealthy)
  - wool
    - Flemish textile manufacturers
- English army
  - feudal levies
  - English customs
    - wool
    - English assets
      - (vassals)
- Papal administrators
  - Papal assets
    - (bishops)
  - Florentine textile manufacturers
Final autocatalytic spillover into kinship: Florentine patrilineage

Not “family into company” but “company into family”:

-- cf. Thomas Blomquist (contra Sapori)

Merchant new men (and their syndicates) turned themselves into noble patrilineages

-- using plastic social form of consorteria

-- with recognition and support from their new customers: Church, bishops, kings and aristocrats

Italy thereby moved onto separate evolutionary trajectory from France and most of Europe:

-- merchants and nobility blended, not segregated
General Conclusion

Inventions of new organizational forms in Padgett & Powell book are generated through

A. Recombination of multiple types of social relations across multiple-network domains
   -- We call this innovation

   plus

B. Reproduction through autocatalytic spillovers that tip networks in those domains
   -- We call this invention

This is social-network perspective on evolution.
Chapter 6:
THE EMERGENCE OF PARTNERSHIP SYSTEMS IN RENAISSANCE FLORENCE

John F. Padgett
The Emergence of Organizations and Markets
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• We need a theory of transformational flows, out of which objects and behaviors emerge
Biochemistry as metaphor

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• Origins of life

• Social structure as vortex

• Example of the human body: no atom in your nose was there two years ago
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• “Actors” are composites of production rules, relational protocols, and linguistic addresses.

• Each of these reproduce and recombine as they flow through people and organizations.
3 types of Autocatalysis

• Production autocatalysis
  -- products flow in trade through skills in cells
  -- skills reproduce and die

• Biographical autocatalysis
  -- skills flow through teaching among cells
  -- cells reproduce and die

• Linguistic autocatalysis
  -- symbols flow through addresses (names) of cells, thereby channeling flows
  -- symbols and addresses reproduce and die
Multiple Networks

• Autocatalysis is the emergence of life, but that is not speciation, which is the tipping of one form of life into another

• To get speciation, need multiple autocatalytic networks that interlock and tip each other
  -- multiple networks essential for evolution
  -- otherwise “equilibrium” which is dead
Figure 1. Multiple-network ensemble Renaissance Florence

ECONOMIC:

Guild 2

Guild 1

KINSHIP:

Neighborhood 1

Neighborhood 2

POLITICAL:

Social Class 1

Social Class 2

Social Class 1

Social Class 2

Note: (a) Solid lines are constitutive ties. Dotted lines are relational social exchanges. Oblongs are formal organizations (families and firms.)
(b) People in multiple roles are verticle lines connecting corresponding dots in the domains of activity in which people are active. (Only two are shown for illustration.)
Innovation vs. Invention

• **Organizational Innovation** = cross-domain recombination of networks (vertical Δ in fig)
  -- transposing production or relational practices across domains

• **Organizational Invention** = spillover into tipping domains themselves (horiz. Δ in fig)
  -- making new industries or fields
Network-folding mechanisms of Organizational Genesis

• P&P document eight network-folding mechanisms that created new organizational forms:

1. Transposition and Refunctionality
   -- Renaissance Florentine partnership
   -- biotechnology in contemporary U.S.

2. Incorporation and Detachment
   -- medieval international finance

3. Anchoring Diversity
   -- regional clusters in U.S. life sciences

4. Migration and Homology
   -- stock market in early-modern Netherlands
Network-folding mechanisms of Organizational Genesis (cont.)

(5) Conflict Displacement and Dual Inclusion
    -- Bismarck in nineteenth-century Germany

(6) Purge and Mass Mobilization
    -- Stalin, Gorbachev and Yeltsin in USSR
    -- Mao in Cultural Revolution

(7) Privatization and Business Groups
    -- post-Communist Hungary

(8) Robust Action and Multivocality
    -- Cosimo de’ Medici in Florence
    -- Deng Xiaoping in China
application of theory to Florence ...
(chapter 6)
DV = partnership system

- Previously, unitary patrilineal banks in intl m-b.
- But in 1383, multiple diverse companies linked through single senior partner/investor.
- Economic consequences:
  -- centralized control
  -- partial limited liability
  -- businessman as financier, not entrepreneur
  -- double-entry bookkeeping
  -- dramatic increase in inter-company credit
# Florentine partners in:

**INTL M-B 1369**
- 96
- (23.8% ‘system’)

**DOMESTIC BNK 1369**
- 75
- (18.5% ‘system’)

**WOOL (1382)**
- 309
- (4.3% ‘system’)

Fastelli
INTER-INDUSTRY STRUCTURE, 1385 - 99

# Florentine partners in:

- M-B FOREIGN
  - 99
  - (46.8% ‘system’)

- M-B FIR/PISA
  - 76
  - (45.7% ‘system’)

- DOMESTIC BNK
  - 245
  - (19.4% ‘system’)

- RETAIL
  - (-)

- WOOL (1382)
  - 309
  - (4.3% ‘system’)

- SILK
  - (-)
Figure 4. Cambio Banking Firm Size Distribution

Average Number of Partners per Bank

Industry Size (Total number of Cambio Bankers)

- ▲ 1350-1380
- ■ 1382-1399
1427 intercompany credit (JMH article)
emergence

• Goal is to understand emergence of economic novelty not as “just economics”, but as tipping in multiple networks of Florence.

• Innovation = transposition & refuctionality through politics back into economics

• Invention = absorption in & rewiring of marriage networks of Florentine elite -- thereby making republican-mercantile “Renaissance men”
Transposition & Refunctionality

• Innovation not as new tool for old goal, but rather as new goal for old tool.
  -- “refunctionality” same as
  Stephen Jay Gould’s “exaptation”

• Example of monkey eating ants:
  banana ➔ shovel
Transposition & Refunctionality: Florence

**Transposition:**

CIOMPI REVOLT

Politics

- city council
- economic mobilization
- political co-optation

Economy

- international merchants
- domestic bankers

**Refunctionality:**

Politics

- ex-city councilors
- merchant-republicans

Economy

- international merchants
- domestic bankers
- Partnership systems
Repression of Ciompi revolt

• 1378 violent revolt of wool workers, in name of guild representation -- only ‘successful’ workers’ state in middle ages

• Three stages of repression:
  -- 1378-1382: liberal regime of minor guilds
  -- 1382-1393: regime of moderate major guildsmen, not organized as guilds
  -- 1393-1433: Albizzi “oligarchic” republican regime (also called “civic humanism”)
Transposition:
1382-1393 moderate regime

• Outlawed guilds as political foundation
  -- used *Mercanzia* and *Balie* instead
• International trade had been decimated by previous war with Pope (1376-78)
  -- wool mnfts need to rebuild economy
• Coopted “centrist” businessmen neutrals
  -- especially domestic cambio bankers
  -- into political city council
  -- and sent them overseas to rebuild trade
Refunctionality:
guild master-apprentice into
system senior-junior partners

• Domestic cambio bankers go overseas and do what they knew how to do: master-apprentice -- short-term 3-year contracts
  -- not traditional (for intl m-b) father-son
• Except now not sequential with youngsters, but with multiple experienced businessmen -- who actually know more than they do about the business
embedding in Florentine elite:
# Socio-Political Embedding of System builders

## Poisson regressions

<table>
<thead>
<tr>
<th>Social Class:</th>
<th>Number of Industries</th>
<th>Number of Partnerships</th>
</tr>
</thead>
<tbody>
<tr>
<td>Popolani</td>
<td>1.110</td>
<td>.342</td>
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<tr>
<td>Magnate</td>
<td>[collinear]</td>
<td>.608</td>
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<tr>
<td>New Man</td>
<td>.718</td>
<td>.110</td>
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## Social Class of Wife:

<table>
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<tr>
<th>Social Class of Wife:</th>
<th>Number of Industries</th>
<th>Number of Partnerships</th>
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</thead>
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<tr>
<td>Popolani</td>
<td>.736</td>
<td>.673***</td>
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<tr>
<td>Magnate</td>
<td>.559</td>
<td>.365</td>
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<tr>
<td>New Man</td>
<td>1.722</td>
<td>.497</td>
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## Political Office:

<table>
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<th>Number of Industries</th>
<th>Number of Partnerships</th>
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</thead>
<tbody>
<tr>
<td>Priorate</td>
<td>-2.144</td>
<td>-.288</td>
</tr>
<tr>
<td>Calimala Consul</td>
<td>[∞]</td>
<td>.985*</td>
</tr>
<tr>
<td>Cambio Consul</td>
<td>1.572*</td>
<td>.198</td>
</tr>
<tr>
<td>Lana Consul</td>
<td>.907</td>
<td>-.744*</td>
</tr>
<tr>
<td>Mercanzia</td>
<td>1.909</td>
<td>-.345</td>
</tr>
</tbody>
</table>

## Political Factions:

<table>
<thead>
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<th>Political Factions:</th>
<th>Number of Industries</th>
<th>Number of Partnerships</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albizzi</td>
<td>[-∞]</td>
<td>.726</td>
</tr>
<tr>
<td>Ricci</td>
<td>.602</td>
<td>-.333</td>
</tr>
<tr>
<td>Anti-ciompi</td>
<td></td>
<td>.331</td>
</tr>
<tr>
<td>Pro-ciompi</td>
<td></td>
<td>-.818</td>
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</tbody>
</table>

## Quarter:

<table>
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<th>Number of Industries</th>
<th>Number of Partnerships</th>
</tr>
</thead>
<tbody>
<tr>
<td>Santa Croce</td>
<td>1.187</td>
<td>-.217</td>
</tr>
<tr>
<td>Santa M. Novella</td>
<td>.126</td>
<td>-.345</td>
</tr>
<tr>
<td>San Giovanni</td>
<td>-.022</td>
<td>.042</td>
</tr>
</tbody>
</table>

*** = (p < .001); ** = (p < .01); * = (p < .05)
Figure 3a. Cambio Bank Membership in Priorate

Percentage in Priorate

Period

1348-62 1363-76 1380-89 1390-99 1427

Partnerships

Bankers
Figure 3b. Cambio Bank Membership in Mercanzia

- **Partnerships**
- **Bankers**
Figure 4a. Cambio Bank Marriage to Popolani Wife

Percentage with Popolani wife (marriage before end of period)

Period:
- 1348-62
- 1363-76
- 1380-89
- 1390-99
- 1427

Graph types:
- Partnerships
- Bankers
Figure 4b. Cambio Partnership Intermarriage

The graph shows the percentage of partners' extended families intermarried (marriage before end of period) over different periods:

- 1348-62
- 1363-76
- 1380-89
- 1390-99
- 1427

The data indicates a gradual increase in intermarriage over time.
Figure 4. Number of Cambio Bankers, by Social Class, in 14th century
Figure 6. Domestic Banker's Wealth Distribution
Business consequences:
### Relative Experience of Non-family Cambio Banking Partners
(including non-family subset of mixed companies)

#### 1348-1376:

<table>
<thead>
<tr>
<th>Experience</th>
<th>Less Experience in Cambio Banking:</th>
<th>%MExp.&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>More</td>
<td>Overall Δ</td>
</tr>
<tr>
<td></td>
<td>P</td>
<td>NM</td>
</tr>
<tr>
<td>Popolani</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>New Men</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>N.N. Men</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Magnates</td>
<td>--</td>
<td>-</td>
</tr>
<tr>
<td>No Date</td>
<td>--</td>
<td>-</td>
</tr>
<tr>
<td>Overall Δ</td>
<td>---</td>
<td>--</td>
</tr>
<tr>
<td>Total n</td>
<td>373</td>
<td>95</td>
</tr>
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</table>

#### 1380-1399:

<table>
<thead>
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<th>Experience</th>
<th>Less Experience in Cambio Banking:</th>
<th>%MExp.&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>More</td>
<td>Overall Δ</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>NM</td>
</tr>
<tr>
<td>Magnates</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>New Men</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>No Date</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>N.N. Men</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Popolani</td>
<td>--</td>
<td>0</td>
</tr>
<tr>
<td>Overall Δ</td>
<td>--</td>
<td>-</td>
</tr>
<tr>
<td>Total n</td>
<td>137</td>
<td>144</td>
</tr>
</tbody>
</table>

N.B.: “+” ≡ [(i,j) - (j,i)] ≥ 10; “++” ≡ [(i,j) - (j,i)] ≥ 50
“-” ≡ [(i,j) - (j,i)] ≤ -10; “--” ≡ [(i,j) - (j,i)] ≤ -50
Florentine adoption of Bilateral Double-entry bookkeeping

- 1259-1299: 0/10 = 0% acct bks *contrapposto*
- 1300-1349: 0/7 = 0% acct bks *contrapposto*
- 1350-1377: 0/3 = 0% acct bks *contrapposto*
- 1382-1399: 5/5 = 100% acct bks *contrapposto*
- 1400-1427: 12/15 = 80% acct bks *contrapposto*

Source: our survey of the ASF account books in Goldthwaite’s two archival lists.
Relational vs transactional exchange

• But d-e accounting **not** equal to impersonal

• Our *Journal of Modern History* article (2011) demonstrated deep social embedding of business credit
  -- essentially gift exchange
  -- especially in most advanced financial capitalist segments of economy

• Double-entry accounting did not abolish social exchange, it mathematized it
1427 intercompany credit (JMH article)
Linear perspective in art

• Timing of adoption of d-e bookkeeping and invention of linear perspective almost the same. Coincidence?
  -- i.e., Brunelleschi, Masaccio, Alberti
• Both portray figures in abstract mathematical space
  -- arrays of tiles on floor in painting
  -- arrays of current accounts in bookkeeping
• “Renaissance men” were patrons/buyers of the art
  -- actively negotiated content in contracts
• Artists & scientists gradually coopted into elite
  -- no longer anonymous artisans
Consequences for Renaissance elite:

• Rise of hybridized republican-mercantile “Renaissance man”:
  -- business as patronage, and patronage as business
  -- *amicizia* (friendship) = *utile* (profit)
  -- in politics, patronage replaces guild as core political network foundation
  -- indeed arguably “patronage” as entirely new type of network tie emerged
Open elite

• Innovation, not just corruption, because of
  -- open elite (see my RQ article), with
  -- intense status competition
  -- across orthogonal status dimensions

• Family itself also transformed:
  -- core constitutive bond rekeyed from patrilineal (father-son) to parentado (marriage in-laws)
  -- more money in dowries than in inheritance
  -- middle classes feverishly mimic vanishing upper-class patrilineage as cultural ideal
Conclusion

• Florentine case primarily an illustration of biographical autocatalysis:
  -- business careers tipped through politics
  -- republican-business biographies reshaped through marriage
  -- control through “open elite” cooptation

• *In the short run, actors make relations, but in the long run relations make actors.*
  -- anonymous moderates and domestic cambio bankers made the Renaissance
  -- “geniuses” were consequences, not causes
Postscript

I want to close with a special note of thanks to Harrison White. Many people have influenced me—indeed have spoken through me—but Harrison more than anyone else injected in me the simultaneous commitment to history and to science. Harrison’s history side was more obvious in his teaching than in his research, but he was and is a mensch—an aspiration for every network analyst alive.
Chapter 9: The Politics of Communist Economic Reform: Soviet Union and China

John F. Padgett
The Emergence of Organizations and Markets
Co-evolution

• Padgett/Powell’s *Emergence of Organizations and Markets* makes general argument that
  -- evolutionary novelty in organizations comes from spillover and rewiring across multiple social networks

• In Soviet Union and China, that means:
  -- politics induced by economic reform, and
  -- economics induced by political reform
Emergence of Organizations and Actors

• P/P mantra:
  
  *In the short run, actors make relations.*
  
  *But in the long run, relations make actors.*

• In Soviet Union and China, that means:

  -- Over time, reforms induce interests and informal social networks that feedback to reshape both reforms and the leaders who made them.
Communist Dual Hierarchy

Economic pillar:
- Council of Ministers
- Economic Ministries
- State Enterprises

Political pillar:
- Politburo
- Central Committee
- Provincial Secretaries
- Local Government

Leader

(selection)
Reform trajectories

Dual hierarchy presented only four potential political constituencies to reform-minded CP leaders. Thus, only four viable trajectories of internal evolution:

1. Through top of Economy  
   -- economic ministries
2. Through bottom of Economy  
   -- factory directors
3. Through top of Party  
   -- party secretaries
4. Through bottom of Party  
   -- local cadres
Reform trajectories
(historical examples of the four types)

1. Through top of Economy:
   -- Stalin’s WWII mobilization:
       central command economy
   -- Brezhnev’s scientific tinkering
   -- Andropov’s KGB discipline

2. Through bottom of Economy:
   -- Kádár’s Hungarian socialism
   -- Kosygin’s failed attempt at economic liberalization
   -- Gorbachev’s Law on State Enterprises (*Perestroika*)
Reform trajectories
(historical examples of the four types)

3. Through top of Party:
   -- Stalin’s First Five-Year Plan
   -- Mao’s Great Leap Forward
   -- Deng’s market liberalization ("robust action")

4. Through bottom of Party: “purge and mass mobilization”
   -- Stalin’s Great Terror
   -- Mao’s Cultural Revolution
   -- Gorbachev’s “Democracy” (escalation of glasnost)
Figure 1.7a. Soviet Central Command Economy: Genesis

**Purge and Mass Mobilization:** THE GREAT TERROR of 1937-38
Figure 5. Input–output interaction of the arms industry and heavy industry

Key: A thin arrow pointing in a single direction indicates a one-way flow of products from supplier to user. A broad arrow pointing in both directions indicates a two-way product flow with each sector consuming part of the other's output.

Notes: In order to read the diagram, start on the left-hand side with the armed forces and follow each product flow backwards to its source. Two sectors—the transport and construction industries—are not represented explicitly but are implicitly present. Each arrow represents spatial flows requiring transport services for their realisation; to deliver its services, the transport industry requires inputs of machinery and fuel. Moreover, each of the supplying sectors in the diagram requires receipt of built capacity from the construction industry before it can use current inputs or supply outputs.
China

Mao’s Great Leap like Stalin’s First Five-Year Plan
-- except agricultural, and
-- decentralized (Khrushchev’s sovnarhkozy)

Mao’s Cultural Revolution like Stalin’s Great Terror
-- Red Guards ≈ Stakhanovites
-- PLA ≈ secret police
-- but PLA + Red Guards don’t connect as well as secret police + Stakhanovites
Chinese economic enterprises after Great Leap

Central

Provincial

Local

□ = governmental /party units  ○ = economic units

→ = authority relations
which leads to vertical factions

Chairman

Central committee

factions

province 1: Party within economy
province 2: Party within economy
province 3: Party within economy
Deng Xiaoping

Mao made accessible what Deng achieved:

-- administrative decentralization
-- personal vertical factions
-- Cultural Revolution acted as “creative destruction”
-- Gorbachev had none of this to work with

Deng’s “market reforms” really communist strategy #2:

-- “play to provinces”
-- But addition of (post-Cultural Revolution) PLA
-- equaled “robust action”
Deng’s Robust Action

Figure 4. Deng Xiaoping’s economic reform and political transition:

- CPCC
  - Chinese military
  - elders (DX)
  - CAC & MAC

- central govt = central CP
  - conservative faction (HG/LP)
  - DX
  - economic reform

- local govt = local CP
  - reform faction (HY/ZZ)
  - local business
  - (market)

- state enterprises
  - (plan)

(Tiananmen Square)
Chinese Markets from robust action

-- residues from Mao:
  vertical political factions, non-red PLA, & regional economic autarchy

-- mobilized into “markets” in economics through clientage in political factions:
-- local government as entrepreneur (no pvt. property)
  -- household responsibility
  -- local light industry
  -- provincial finance

-- macro policy oscillation during Deng’s reign
  -- like chemical annealing
Gorbachev

on other hand, rapidly escalated from constituency-trajectory #1 to #4:

1. Through top of Economy (KGB)
   -- Andropov-style discipline
2. Through bottom of Economy
   -- Hungarian market socialism
4. Through bottom of Party
   -- Glasnost & soviets (within CP)
   -- which eventually spun out to Democracy (outside CP)
Gorbachev’s core problem same as Stalin’s: Family circles

- Moscow ministry
- Moscow Communist Party
- Management teams
- Worker councils
- State enterprise
- CP cell
Soviet Dual Hierarchy, without and with Gorbachev’s extension to soviets

Solid line = formal authority; dotted line = informal adaptations.
In Soviet Union, formal centralization induced horizontal informal alliance networks to circumvent it.

In China, formal decentralization (sovnarhkozy) induced vertical informal alliance networks to circumvent it.

Except within Kremlin, Gorbachev thus had no personal patron-client network with which to break through autocatalytic layers of Soviet family circles.

Leaving him only nuclear option #4:

“purge and mass mobilization”
-- in name of “democracy”
-- Gorbachev pushed to become a failed Stalin
Conclusion

- Large-scale transitions never evolve by design
  - tumultuous system tippings beyond anyone’s control
  - instead large-scale transitions are re-wirings of path-dependent pieces into finite accessible trajectories

- In cases of Soviet Union & China,
  - Mao made accessible what Deng achieved
  - Stalin structured not only what Gorbachev fought against, but also Gorbachev himself
Chapter 13: Chance, Necessité, et Naïveté: Ingredients to create a new organizational form

Walter W. Powell    Kurt Sandholtz
Motivating question: Where do new practices and models of organization come from?

- Focus on components – separable parts that are assembled in novel ways
- "Lash up" (Law 1984; Latour 1987)
  - How do diverse elements become interactively stable?
- Why are certain building blocks, but not others, incorporated into a new enterprise?
- How do re-purposed practices reverberate back into the domains from which they were borrowed?
Organizational and technical change: a pragmatist view

• When established routines prove lacking, people search and experiment.
• People draw on stock of existing knowledge to forge new tools for coping with situations without precedent.
• Individuals who repurpose old tools are “moral entrepreneurs” or “rule creators” (Becker 1963).
• People who cross formerly separate domains are trespassers – not boundary-spanners doing import and export.
• Traffic across social worlds creates new social spaces, which may be unencumbered by the baggage of established practices.
Building on Schumpeter, Nelson & Winter

- Schumpeter (1939: 85): “The making of the invention and the carrying out of the corresponding innovation are, economically and sociologically, two entirely different things.”

- All novelty is “a recombination of conceptual and physical materials that were previously in existence” (Nelson and Winter, 1982: 130).

- We argue it matters a great deal whether recombination occurs on familiar terrain or happens in a new setting where the components are foreign.
Recombination v. Transposition

- **Recombination**: Moving practices from one sector into another where they are recognizable (*i.e.*, computing to digital cameras, Hollywood film to theatre, telephones with video)

- **Transposition**: Moving practices into settings where they are foreign; a boundary crossing (*i.e.*, science or religion into commerce)
  - Less frequent, and much less likely to be successful
  - But even failures at trespassing can generate “fresh” action that can have profound tipping effects
Data and Methods

• Historical multi-case analysis
  – Reliance on first-hand, founders’ accounts from the time period
  – 1,800 pages of oral histories in UC-Berkeley Bancroft Library collection
  – Supplemented with new interviews with founders, board members, and VCs

• Rationale

“A major source of this difficulty [demarcating an unambiguous start or origin of an activity, industry, or population] occurs, we think, because we lack the analytical framework to identify and describe the early steps in industry or form emergence.... As a next step, ethnographic and other qualitative research might prove extremely useful in simply identifying and describing interesting relevant cases.” (Hannan, Polos & Carroll 2007: 58)
Fertile ground for studying emergence

- Life science research breakthroughs outpaced capabilities of established firms.
- New enthusiasm and legal support for university-industry technology transfer.
- ERISA and “Prudent Man” rulings permitted pension funds and endowments to be invested in high-risk VC funds.
- BUT: *poisedness does not imply predictability!* No evidence that there was any blueprint for a new organizational model.
## Sample of First-Generation Companies

<table>
<thead>
<tr>
<th>Company</th>
<th>Founding Year</th>
<th>Location</th>
<th>Founding Model</th>
<th>Currently</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALZA</td>
<td>1968</td>
<td>Palo Alto, CA</td>
<td>“A great place if it were a nonprofit think tank”</td>
<td>No longer in existence</td>
</tr>
<tr>
<td>Cetus</td>
<td>1972</td>
<td>Emeryville, CA</td>
<td>Academic playground or “Free Space”; biotech tools would be applied to a host of problems</td>
<td>No longer in existence</td>
</tr>
<tr>
<td>Genentech</td>
<td>1976</td>
<td>South San Francisco, CA</td>
<td>“Best of both worlds”; serious science and VC funding create a new model for basic research</td>
<td>Subsidiary of Roche</td>
</tr>
<tr>
<td>Genex</td>
<td>1977</td>
<td>Montgomery, MD</td>
<td>Low-cost producer: apply biotech methods to the manufacture of industrial chemicals</td>
<td>No longer in existence</td>
</tr>
<tr>
<td>Biogen</td>
<td>1978</td>
<td>Geneva, Switzerland</td>
<td>Transatlantic network of world-class scientists</td>
<td>Biogen Idec</td>
</tr>
<tr>
<td>Hybritech</td>
<td>1978</td>
<td>La Jolla, CA</td>
<td>New diagnostic tools for the war on cancer</td>
<td>No longer in existence</td>
</tr>
<tr>
<td>Centocor</td>
<td>1979</td>
<td>Philadelphia, PA</td>
<td>Bridge between academia and commercial health care</td>
<td>No longer in existence</td>
</tr>
<tr>
<td>Amgen</td>
<td>1980</td>
<td>Thousand Oaks, CA</td>
<td>To become a FIPCO (fully integrated pharmaceutical company)</td>
<td>Independent</td>
</tr>
<tr>
<td>Chiron</td>
<td>1981</td>
<td>Emeryville, CA</td>
<td>“Get in or lose out”: tired of losing top scientists to biotech ventures, UCSF department chair starts his own company</td>
<td>No longer in existence</td>
</tr>
<tr>
<td>Genzyme</td>
<td>1981</td>
<td>Boston, MA</td>
<td>Niche collector; “Company of singles rather than home runs”</td>
<td>Subsidiary of Sanofi-Aventis</td>
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<tr>
<td>Immunex</td>
<td>1981</td>
<td>Seattle, WA</td>
<td>Academics find a “pugnacious” entrepreneur willing to back “underdog” scientists</td>
<td>No longer in existence</td>
</tr>
</tbody>
</table>

*Table 13.1*
There was no blueprint for a science-based company

- Brook Byers, VC backer and first CEO of Hybritech:
  “We were naïve. I think if we had known everything about all the potential huge competitors, we might not have even done it. One of the benefits we had, I suppose, was some combination of naïveté and ambition and this desire to do something on our own...I think there was a feeling of a green field, and that we were the first. We didn’t know all the answers, but we had time to figure it. . . . We did not have the business model mapped out, or the ultimate value proposition, which are all things that we do today in doing a startup. We’re much more sophisticated now. Back then, we didn’t have any of that.”
Tom Perkins on financing Genentech

“What was so different about Genentech was the astonishing amount of capital required to do all of this. I know, on day one, if anyone had whispered into my ear that, ‘for the next twenty years you will be involved in raising literally billions of dollars for this thing,’ I might not have done it. But in 1979, it occurred to me that for something of this importance, that there was enough money out there for us to do whatever we needed to do. I always viewed my role – my ultimate responsibility – was to make sure that the company didn’t run out of money. That was my job. [CEO Robert] Swanson’s job was to make sure the company deserved more money, at ever increasing prices. We both had a pretty clear notion of that. It worked for a long time. Hence, all the different things that we did – the private rounds, the research partnerships, the public rounds, and all the deals. It was always more capital than I anticipated. It dawned on Swanson before it dawned on me. I can’t remember at what point it dawned on me that Genentech would probably be the most important deal of my life, in many terms – the returns, the social benefits, the excitement, the technical prowess, and the fun. By 1979 I was a total Genentech junkie.”
The Dedicated Biotech Firm (DBF), a New Organizational Model

• Operated according to different principles from the traditional corporate hierarchy. Key components:
  – Strong commitment to publishing research results in top science journals
  – Horizontal structure of information flow; project-based organization of work
  – Porous organizational boundaries; a strategy of pursuing innovation through collaborative ventures
  – A heavy reliance on intellectual capital
  – Often produced no marketable products

• In sum, an odd mixture of elements from three distinct domains: science, finance, and commerce
## Distinctive Features of Early Biotech Firms

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<tr>
<td>All-star science</td>
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<td>&quot;Virtual&quot; start-</td>
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<td>Scientific founders</td>
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<td>Scientific founders</td>
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<td>entrepreneurs and/or VCs</td>
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<td>Recruited senior</td>
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<td>exec from Baxter</td>
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<td>to run the</td>
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<td>diagnostic products; avoided long clinical trials</td>
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### Table 13.2

**FINANCE**
- Went public with no products, breakthroughs, or revenues
- Used research partnerships with big pharma to generate funds
- All-star science advisory board
- Campus-like setting near a major research university
- "Free space" for scientists
- Scientific founder stayed at university full-time, consulted with company
- "Virtual" start-up: all initial research conducted by contract with UCSF and City of Hope Hospital
- International consortium of top academic labs (i.e., science advisory board was the company)
- "Virtual" start-up: all initial research conducted in founders' labs
- Scientific founders stayed at their respective universities full-time
- Scientific founder stayed at university full-time, consulted with the company
- Key founding role for talented lab assistant
- Campus-like setting near a major research university (UCSD) and research institute (Salk)
- Scientific founder was first CEO
- First company to commercialize monoclonal antibody technology for diagnostics
- Venture capitalist was first CEO
- First company to commercialize biotech production of industrial chemicals
- Early investment in manufacturing plant
- Scientific founder went on to start additional biotech firms
- Targeted blockbuster medicines
- Scientific founders ran the company for first seven years
- Scientific founders became serial entrepreneurs and/or VCs
- Recruited senior exec from Baxter to run the company
- Focused on diagnostic products; avoided long clinical trials

### Table 13.2

**COMMERCE**
- Founder went on to start numerous biotech firms
- Wide range of commercial applications for biotech
- Swing for the fences – focus on blockbuster medicines
- Pursued low-cost, high-volume strategy (e.g., biotech production of industrial chemicals)
- Early investment in manufacturing plant
- Scientific founder went on to start additional biotech firms
- Targeted blockbuster medicines
- Scientific founders ran the company for first seven years
- Scientific founders became serial entrepreneurs and/or VCs
- Recruited senior exec from Baxter to run the company
- Focused on diagnostic products; avoided long clinical trials
- Scientific founders stayed at university full-time, consulted with the company
- Key founding role for talented lab assistant
- Campus-like setting near a major research university (UCSD) and research institute (Salk)
# Distinctive Features of Early Biotech Firms

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<tr>
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<tbody>
<tr>
<td><strong>SCIENCE</strong></td>
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<td></td>
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</tr>
<tr>
<td>♦ Aggressive in-licensing of research from public science</td>
<td>♦ All-star science advisory board</td>
<td>♦ Founders stayed at universities initially</td>
<td>♦ Transfer of founder’s existing research grant from university (Tufts) to company</td>
<td>♦ Insisted that scientists publish and make contributions to public science</td>
</tr>
<tr>
<td>♦ Initially located in a business incubator on Univ. of Pennsylvania campus</td>
<td>♦ Skills of academic administration applied to business</td>
<td>♦ Insisted that scientists publish and make contributions to public science</td>
<td>♦ Key founding role for talented lab assistant</td>
<td>♦ Founding scientists resigned from academic jobs to avoid conflict of interest</td>
</tr>
<tr>
<td>♦ Close relationship with research institute (Wistar)</td>
<td>♦ Transfer of founder’s existing research grant from university (UCSF) to company</td>
<td>♦ Used research partnerships with pharma and universities as a mode of exploration</td>
<td>♦ Hired science advisory board intact (i.e., Bio-Information Associates, a consulting firm of MIT and Harvard profs)</td>
<td>♦ Campus-like setting near a major research university (U. of Washington) and research institute (Hutchinson Cancer Center)</td>
</tr>
<tr>
<td><strong>FINANCE</strong></td>
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<tr>
<td>♦ IPO as salvation, despite no products, or patented breakthroughs.</td>
<td>♦ Used tracking stocks to compartmentalize risk</td>
<td>♦ Out-licensed early patents to large pharma, then later reacquired them</td>
<td>♦</td>
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<tr>
<td><strong>COMMERCE</strong></td>
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<tr>
<td>♦ Bridge between academic labs and biopharma manufacturing/marketing</td>
<td>♦ Recruited senior exec from Abbott’s diagnostics division to run the company</td>
<td>♦ Focused on large potential market underserved by big pharma: vaccines</td>
<td>♦ Founder was serial entrepreneur from the packaging industry</td>
<td>♦</td>
</tr>
<tr>
<td>♦ Recruited senior exec from Corning’s medical products business to run the company</td>
<td>♦ Novel decision-making process for allocating resources to projects</td>
<td>♦ Scientific founders ran the company</td>
<td>♦ Focus on niche markets and orphan drugs</td>
<td>♦</td>
</tr>
<tr>
<td>♦ Focused on diagnostic products</td>
<td>♦</td>
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Table 13.2
The DBF is a composite, not an ideal type

• No company had all of the elements of the eventual model.
• Unclear if any of the participants were aware that they were creating a novel organizational form.
  – Some chafed under the constraints of existing organizational practices.
  – Others wanted to experiment with new conditions and rules.
Novelty flowed from “improvisational trespassers”

• “Amphibious” scientists traveled between formerly separate domains, bringing new tasks into the confines of existing settings until such arrangements no longer proved viable.

• Examples:
  – Genentech: a virtual company for two years, operating out of labs at UCSF and City of Hope hospital.
  – Biogen: first breakthrough came from the lab of one of its founders at the University of Zurich.
  – Centocor: began by licensing a patent for a monoclonal antibody developed by two of its founders at the Wistar Institute on the University of Pennsylvania campus.
## Clusters of Characteristics Suggest Two DBF Variants

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<tr>
<td>Insisted that scientists publish their findings</td>
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<td>X</td>
<td>X</td>
<td>X</td>
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<td>Campus-like setting near a major research university</td>
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<td>Founder(s) continued at or returned to university or institute</td>
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<td>X</td>
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<td>X</td>
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<td>All-star science advisory board</td>
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<td>X</td>
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<td>FINANCE</td>
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<td>Research contracts with large corporations</td>
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<td>Active VC involvement in early management</td>
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<td>IPO with no products or predictable revenue stream</td>
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<td>Founder(s) already had entrepreneurial track record</td>
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<td>Early hiring of senior exec from health care or pharma</td>
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<td>Scientific founder(s) subsequently became serial entrepreneur(s)</td>
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<td>Initial emphasis on non-therapeutic applications</td>
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*Note: This analysis was created by coding for the presence/absence of distinctive elements*
Two Variants of the DBF Form

<table>
<thead>
<tr>
<th>A Science-Centered Variant</th>
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</thead>
<tbody>
<tr>
<td>• Science is central, supported by funding and management</td>
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<tr>
<td>• Renowned scientist-founders straddle domains, often occupying key executive and academic roles simultaneously</td>
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<tr>
<td>• Scientific Advisory Board is peer review</td>
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<td>• Strong commitment to publishing research results</td>
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<td>• VCs invest “scientifically”: minimal funding of initial experiment (proof of principle), followed by increasing investments</td>
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<td>• Investors place bets on proven scientific accomplishments</td>
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<tr>
<td>• Academic headwaters: William Rutter’s interdisciplinary UCSF lab</td>
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<td>• Commercial headwaters: ALZA Corp.</td>
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<tr>
<td>• Exemplars: Genentech, Biogen, Chiron, Immunex</td>
</tr>
<tr>
<td>• Failed attempt: Cetus (lacked strong scientific leader)</td>
</tr>
<tr>
<td>• Mechanism of genesis: transposition</td>
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</table>

<table>
<thead>
<tr>
<th>A Commerce-Centered Variant</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Commerce is central, supported by funding and science</td>
</tr>
<tr>
<td>• Scientifically-trained business play crucial early roles</td>
</tr>
<tr>
<td>• Scientific Advisory Board is signal of approval</td>
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<tr>
<td>• Publishing is not encouraged</td>
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<tr>
<td>• VCs invest traditionally: focus on markets, products, etc.</td>
</tr>
<tr>
<td>• Commercial headwaters: entrepreneurial divisions of health care or pharma co.s (Baxter, Abbott, Corning)</td>
</tr>
<tr>
<td>• Exemplars: Hybritech, Centocor, Amgen, Genzyme</td>
</tr>
<tr>
<td>• Failed attempt: Genex (lacked strong commercial leader)</td>
</tr>
<tr>
<td>• Mechanism of genesis: recombination</td>
</tr>
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Table 13.4
### Table 13.5: Commerce- v. Science-Centered: Publication and Citation Counts*

<table>
<thead>
<tr>
<th>COMPANY</th>
<th>YEAR OF IPO</th>
<th>TOTAL PUBS</th>
<th>AVG PUBS/YR</th>
<th>TOTAL CITATIONS</th>
<th>AVG CITES/PUB</th>
<th>H-INDEX¹</th>
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<tbody>
<tr>
<td>COMMERCE</td>
<td></td>
<td></td>
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<tr>
<td>Alza</td>
<td>1969</td>
<td>116</td>
<td>11.6</td>
<td>2,608</td>
<td>22.48</td>
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<tr>
<td>Genex</td>
<td>1982</td>
<td>163</td>
<td>16.3</td>
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<td>272</td>
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</tr>
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<td>Cetus</td>
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<td>1,000</td>
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<td>107,469</td>
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<td>146</td>
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<tr>
<td>Genentech</td>
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<td>1,656</td>
<td>165.6</td>
<td>198,608</td>
<td>119.93</td>
<td>218</td>
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<tr>
<td>Biogen</td>
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<td>623</td>
<td>62.3</td>
<td>54,272</td>
<td>87.11</td>
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<td>90.5</td>
<td>86,453</td>
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<td>Immunex</td>
<td>1983</td>
<td>710</td>
<td>71</td>
<td>61,616</td>
<td>86.78</td>
<td>133</td>
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|                | t-test (1-tail) | 0.009 | 0.009 | 0.004 | 0.003 |

¹The h-index is a measure of publication quality and quantity. To derive h, each company's publications are listed in descending order by times cited. The value of h equals the number of papers (N) in the list that have N or more citations. Source: ISI Web of Science®.

* Publication and citation data are from the 10-year period following initial public offering.
A Traditional Technology-Based Firm

- Rectangles represent the three domains
- Circles represent autocatalytic flows within the domain
- Triangle is a new venture
- Technology arrow indicates a one-way transfer, with little exchange between the Science domain and the other domains

Figure 13.1
A Science-Centered Variant of the DBF

- Renowned scientists transposed academic culture into the venture-backed firms
- Scientific output was repurposed as investment worthiness; investment capital was repurposed as support for basic research
- Scientific founders typically returned to academia, or become angel investors or VCs rather than serial entrepreneurs
Senior executives from pharma or healthcare companies brought a commercial focus to the DBF. Firms following this model were more likely to pursue lower-risk, quicker-return diagnostic products. Founders of these firms tended to become serial entrepreneurs rather than investors; few returned to academia.
The Creation of Novelty, Step-by-Step

<table>
<thead>
<tr>
<th>Established routines prove lacking . . .</th>
<th>Traditional corporate R&amp;D model is too insular and proprietary for biotech’s purposes; in addition, top-flight researchers are unwilling to leave the academy unless the <em>research</em> (not just economic) opportunities are abundant.</th>
</tr>
</thead>
<tbody>
<tr>
<td>. . . so founders draw on existing knowledge . . .</td>
<td>Scientific founders import the invisible college into a corporate setting, minus the grant-chasing and tenure struggles.</td>
</tr>
<tr>
<td>. . . and scan their social worlds for cues . . .</td>
<td>Top scientists look to each other for validation of commercial involvement, and judge legitimacy of a new firms using their customary criteria: quality of scientific output (i.e., publishing). At the same time, they assess the “new” world of commerce, and realize the importance of patenting prior to publication.</td>
</tr>
<tr>
<td>... forging unique elements of a science-based organizational form.</td>
<td>R&amp;D becomes a porous, networked endeavor whose results are published in the top journals. New career paths are established for academic life scientists.</td>
</tr>
</tbody>
</table>

*Table 13.6*
Robert Swanson on publishing at Genentech

“[Scientific founder Herb] Boyer’s philosophy, which I agreed with, was that you gain more from interaction with your academic peers than you give up by telling the competition where you are. So with interaction you can move quicker; you gain more people willing to collaborate with you. We knew then we weren’t going to have all the best ideas, and we said, ‘Where do the academic scientists go when they have an idea that they think needs to be commercialized? We want them to think of us first. We want them to come to Genentech first, because this is a group of scientists that are well published and that a university scientist would be proud to collaborate with on a scientific basis, and where I know they can get this product developed and make it available.’ So that was a goal from the very beginning.”
Steve Gillis on doing science at Immunex

“We encouraged scientists within the company to publish their findings, to speak at meetings. . . . [T]hat resulted in spreading the influence of the company, and actually allowed us to get collaborators who otherwise might not have been open to collaborating with us.

“Genentech would publish in their annual report . . . a graph of how many times Genentech scientists were cited versus other companies. And they were proud that they were always in a leadership position. But we were always either second or third. That was something that gave us pride, and, believe it or not, in the early days, Wall Street analysts looked at that, too. Obviously, those days are long gone.”
## The Creation of Novelty, Step-by-Step

<table>
<thead>
<tr>
<th>FINANCE</th>
</tr>
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<tbody>
<tr>
<td><strong>Established routines prove lacking . . .</strong></td>
</tr>
<tr>
<td><strong>. . . so founders draw on existing knowledge . . .</strong></td>
</tr>
<tr>
<td><strong>. . . and scan their social worlds for cues . . .</strong></td>
</tr>
<tr>
<td><strong>. . . forging unique elements of a science-based organizational form.</strong></td>
</tr>
</tbody>
</table>

*Table 13.6*
Tom Perkins on “financial engineering”

“At IPO, the stock] came out at $35, shot up to $85, then drifted back down. . . . It established the idea that you could start a new biotechnology company, raise obscene amounts of money, hire good employees, sell stock to the public. Our competitors started doing all of that, so much so that we started to lose employees to other biotech startups.

“Our employees had originally acquired our stock as common stock. We were able to justify a 10:1 difference in price. So if the preferred stock was at $35 a share, then employees got common at $3.50 a share. . . . But once it becomes a public stock, the preferred shares convert to common and everyone is on the same platform. So how are we going to continue to attract and hold these people? It was a big problem.
“We got an opinion from the accountants that this stock was worth $\frac{1}{10}$th of what the regular common stock was worth, and we called it junior common stock. It would convert to ordinary common stock in case of certain events. . . . events they had to work towards which have a risk factor.

“We diddle that formula over about four years, we were able to use that form of stock to attract and hold key employees. We were the first company to ever have such a thing. . . . We were very careful to run these plans through the SEC. They approved it. We never had to retract any of that stock. However, the idea was stolen by all of our competitors and so grossly abused that the SEC made most of our competitors retract and eliminate those stock plans.”
The Creation of Novelty, Step-by-Step

<table>
<thead>
<tr>
<th>COMMERCE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Established routines prove lacking . . .</strong></td>
</tr>
<tr>
<td>Barriers to entry in the pharma business are formidable: clinical trials, FDA approval, creation of distribution channels, scaling up manufacturing. Traditional “bootstrap” model (i.e., start small and channel early revenues into growth) was not feasible. There is no such thing as a credible “low-budget” clinical trial, and cutting-edge life-science production processes cannot be easily outsourced to contract manufacturers.</td>
</tr>
<tr>
<td><strong>. . . so founders draw on existing knowledge . . .</strong></td>
</tr>
<tr>
<td>Biotech founders import a proven commercialization model from the world of academia: technology transfer. In this setting, the transfer will be between two for-profit entities, but the resource asymmetries are similar: biotechs have crucial knowledge that big pharma lacks, while big pharma has commercialization capabilities.</td>
</tr>
<tr>
<td><strong>. . . and scan their social worlds for cues . . .</strong></td>
</tr>
<tr>
<td>To remain viable as commercial entities, however, fledgling biotechs must aggressively negotiate the terms of such technology transfers. Access to legal counsel (typically via their VC’s network) becomes crucial, as biotechs learn to “sell” their scientific advances to pharma partners without jeopardizing their future independence.</td>
</tr>
<tr>
<td><strong>... forging unique elements of a science-based organizational form.</strong></td>
</tr>
<tr>
<td>As a result, a wide variety of partnerships are created between small, science-rich biotechs and large, wealthy product-driven pharmaceutical companies. Many of these bargains prove Faustian, as biotechs forfeit ownership and control in exchange for resources.</td>
</tr>
</tbody>
</table>
Feedback Dynamics

The repurposing of scientific values into commerce catalyzed changes in industry:

• Demise of insular internal R&D lab in Big Pharma
• More dependence on external sources of knowledge
• Creation of corporate nonprofit institutes to do collaborative work
• Funding of postdocs
• Greater encouragement for publishing scientific findings
• Campus-like settings to attract the creative class
• Entrepreneur-in-residence programs at venture capital firms
The scientific achievements of the early biotech firms reverberated back into the academy:

- Academic entrepreneurship has been embraced
- Departments and schools have been restructured to focus on translational research
- Fueled creation of interdisciplinary research centers
- Adoption of metrics to evince innovativeness
- Industry jobs no longer frowned upon
Feedback Dynamics

In both the academy and industry:

• Evolution from discipline/department to projects
• Not a “settlement” (Rao and Kenney, 2008), but a continuing disruption, most notably in careers and rewards
Recombination v. Transposition revisited

An intriguing paradox:

**Recombination** (exemplified by the commerce-centered firms) proved a more robust business model.

**Transposition** (exemplified by the science-centered firms) has had more far-reaching institutional consequences.
## What happened to the first generation?

<table>
<thead>
<tr>
<th>Company</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alza</strong></td>
<td>Ahead-of-his-time founder (Alejandro Zaffaroni) created a prototype for future biotech firms; acquired by Johnson &amp; Johnson in 2001.</td>
</tr>
<tr>
<td><strong>Cetus</strong></td>
<td>First-mover advantage didn’t hold due to lack of focus; acquired in 1991 by Chiron.</td>
</tr>
<tr>
<td><strong>Genentech</strong></td>
<td>Science married to finance created a new model for commerce. Despite resistance, became a fully-owned subsidiary of Roche in 2009.</td>
</tr>
<tr>
<td><strong>Genex</strong></td>
<td>Low-margin business model became unsustainable without investment by corporate partners; acquired in 1991 by Enzon.</td>
</tr>
<tr>
<td><strong>Biogen</strong></td>
<td>“World class research seminar” made corporate governance challenging; licensing model proved robust. Merged with IDEC in 2003.</td>
</tr>
<tr>
<td><strong>Hybritech</strong></td>
<td>Entrepreneurial scientist found world-class VC, who recruited a pharma escapee to run the show. Bred for eventual sale and acquired by Eli Lilly in 1986.</td>
</tr>
<tr>
<td><strong>Centocor</strong></td>
<td>“Academic scavengers” almost lost their company due to FIPCO aspirations. Acquired by Johnson &amp; Johnson in 1999.</td>
</tr>
<tr>
<td><strong>Amgen</strong></td>
<td>Savvy VCs set out to “do biotech right” by recruiting stellar SAB and putting talented pharma veteran in charge, resulting in biopharma titan that is still independent.</td>
</tr>
<tr>
<td><strong>Chiron</strong></td>
<td>Scientist-entrepreneur moved the invisible college to a business setting. Became a wholly-owned Novartis subsidiary in 2006.</td>
</tr>
<tr>
<td><strong>Genzyme</strong></td>
<td>Venture capital group went shopping for a new venture, and built a business around orphan drug opportunities. Acquired by Sanofi-Aventis in 2011.</td>
</tr>
<tr>
<td><strong>Immunex</strong></td>
<td>Despite stellar scientific record, business success came late. Acquired by Amgen in 2002, resulting in the loss of local “Immunoid” culture.</td>
</tr>
</tbody>
</table>
Chapter 14: Organizational and Institutional Genesis: The Emergence of High-Tech Clusters in the Life Sciences

Walter W. Powell    Kelley A. Packalen
Kjersten Whittington
Central concern: Organizational and Institutional Emergence

• What factors make distinctive network configurations possible at particular points in time (history, sequence) and space (geography)? How does a collection of diverse organizations emerge and form an institutional field?

  – The origins of institutions remain largely opaque. Most research works backward from successful cases to fashion an account of why an outcome solved a particular problem or advanced some group’s or entrepreneur’s project.

  – Instead, we start at the stage when a field began, and ask why it failed in most locales and succeeded in only a few. The key to this inquiry is a focus on:

    • The character of nodes (open vs. closed)
    • The location of the relationships (local vs. distant ties)
    • The type of activities (upstream vs. downstream)
    • The sequence of tie formation (science partner vs. pharma partner)
Why such a pronounced pattern of spatial agglomeration?

The leading sources of knowledge and expertise in the life sciences in the late 1970s and early 1980s were widely distributed across U.S. and globally. In the U.S., public policy and political muscle were flexed to support this field’s development. Many regions had a deep stock of endowments -- Philadelphia, New Jersey, Washington, New York, in particular, but arguably Atlanta, Seattle, Houston, and LA as well. But today, nearly 50% of firms and more than 50% of the outcomes (employment, medicines, patents) come from just three regions -- Bay Area, Boston, San Diego.

Geographic propinquity: a critical feature of the emergence and institutionalization of the life sciences field. It was not anticipated given initial founding conditions, nor an obvious outcome, but became self-reinforcing and highly resilient.

What do we mean by self-reinforcing?

An increasing number of participants were attracted, common expectations developed to guide their interactions, and these legacies were sustained by shared cognitive beliefs.
<table>
<thead>
<tr>
<th>Ranking in number of biomedical patents, 1980</th>
<th>Location</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>New York City</td>
<td>extraordinary array of research hospitals, elite universities and medical schools, venture capital and investment banks</td>
</tr>
<tr>
<td>1</td>
<td>Northern New Jersey</td>
<td>home of major U.S. and foreign pharmaceutical companies, Princeton University</td>
</tr>
<tr>
<td>3</td>
<td>Philadelphia</td>
<td>“the cradle of pharmacy” - strong pharmaceutical presence, U Penn, Wistar Institute, Fox Chase Cancer Center</td>
</tr>
<tr>
<td>4</td>
<td>Bay Area CA</td>
<td>UCSF, Stanford, venture capital…but crowding from ICT industries?</td>
</tr>
<tr>
<td>5</td>
<td>Boston</td>
<td>MIT and to lesser extent Harvard (commercial involvement by faculty was initially precluded there), numerous research hospitals</td>
</tr>
<tr>
<td>6</td>
<td>Washington DC metro area</td>
<td>home of National Institutes of Health, Johns Hopkins University Medical School</td>
</tr>
<tr>
<td>7</td>
<td>Los Angeles CA</td>
<td>largest early biotech firm – Amgen, Cal Tech, UCLA, City of Hope Hospital</td>
</tr>
<tr>
<td>8</td>
<td>Research Triangle NC</td>
<td>three universities, major state public policy initiative to build a cluster</td>
</tr>
<tr>
<td>9</td>
<td>Houston TX</td>
<td>U Texas Medical Center, Rice University, MD Anderson Hospital</td>
</tr>
<tr>
<td>10</td>
<td>Seattle WA</td>
<td>Fred Hutchinson Cancer Center, U Washington…large investments by Bill Gates and others in biomedicine in 1990s</td>
</tr>
<tr>
<td>17</td>
<td>San Diego CA</td>
<td>sleepy Navy and tourist town, but UCSD, Scripps, Salk, and Burnham Institutes</td>
</tr>
</tbody>
</table>
Biotechnology firms in U.S., 2002 (n=368)
Which factors explain why clusters formed in some places and not others?

- A diversity of organizational forms and an anchor tenant are critical factors. Both increase the possibility of **transposition**, the results of which are linked to, but more consequential than, the initial conditions.

- **Multiple organizational forms** - a rich soup in which diverse practices and rules can emerge. There are divergent criteria for evaluating success. (This is not unleashed instrumental action, but cognition in the wild.)

- **Anchor tenant** - a position that affords access to several domains. Having different principles of evaluation enables the anchor to repurpose diverse activities. A catalytic anchor protects the openness of the local community and encourages multiple views. Much like a keystone species.

- Diversity and Connectivity are not sufficient. The mechanism is **cross-network transposition**, which allowed ideas to move from one domain to another.

- This is *not* just statistical reproduction in the sense that something unusual diffused & became accepted, but **transposition**: the initial participants brought status & experience garnered in one realm and converted those assets into energy in an unfamiliar domain.
Data sources:

- Contemporary life science organizations, including dedicated biotech firms, large multinational corporations, research universities, government labs and institutes, research hospitals, nonprofit research centers, and venture capital firms.

- Data set covers all the above organizations, as well as their formal inter-organizational collaborations from 1988-2004. Includes data on earlier years, but is left censored so that we were only able to collect full data on firms that were alive in 1988.

- Two-mode network: 691 dedicated biotech firms, 3,000 plus collaborators, 11,000 plus collaborations - both local and global ties

- Field work, archival records, interviews with 100s of scientists and managers in DBFs, universities, pharma cos., govt. institutes, technology licensing offices, VC and law firms.
Method: Network Visualization, with Pajek

- *Pajek* (Slovenian for ‘Spider’) is a freeware package for the analysis and visualization of large networks created by Vladimir Batagelj and Andrej Mrvar and available online at [http://vlado.fmf.uni-lj.si/pub/networks/pajek/](http://vlado.fmf.uni-lj.si/pub/networks/pajek/)

- In Pajek, ‘spring-embedded’ network drawing algorithms enable meaningful representation of social networks in Euclidean space.
  - ‘Particles’ repel one another, ‘springs’ draw attached particles together
  - Drawing algorithms seek a ‘solution’ where the energy of the entire system is minimized, thus minimum energy drawings are produced
  - In these representations, the positions of nodes are generated by the pattern of ties connecting the entire system

- We draw on two such algorithms
  - Kamada-Kawai (KK) (1989) positions connected nodes adjacent to one another and makes euclidean distances proportional to geodesic path length in the network
Boston Biotech Community 1988

Note: Organizations on the circumference are located in Boston but had no contractual relations with other Boston organizations in 1988.
Note: Organizations on the circumference are located in Boston but had no contractual relations with other Boston organizations in 1998.
Summary Results: Boston Biotechnology Community

● Local public research organizations (PROs) were the foundation on which the Boston commercial biotech community was built. R&D ties to local PROs increased rates of DBF patenting.

● The Boston network changed to become more anchored by for-profit firms. Ties to orgs. outside of Boston grew rapidly. As the network expanded, the majority of ties became commercial. The importance of local PROs receded, but their footprint remained. Centrality in the local network continued to have a big impact on patenting.

● Ties to local PROs are leaky (spillovers), while external commercial ties are closed and contractually restricted.

● Public research organizations contribute to cluster formation precisely because they perform commercially important research under academic institutional arrangements.

● Although active commercial participation by PROs catalyzes life science innovation, it may carry the danger of capture by industrial interests.
Boston and Bay Area Local Networks, 1988, 1994, 1999

Note: Thickness of line indicates multiple ties. Source: Owen-Smith and Powell, 2006.
There is no one recipe for successful cluster formation. The initial endowments in the successful clusters were quite different, and different organizations played the role of anchor tenants.

San Francisco Bay Area - - multiple types of transposition:

- First-generation companies collaborated with one another, (Genentech, Chiron) acting like an academic invisible college
- Active engagement of venture capitalists as executives
- Relational model of technology transfer developed at Stanford
- Interdisciplinary science at UCSF
- Blending of public and private science

It is the cooking, not the ingredients
A sleepy Navy and tourist town became a high tech cluster in biotech and wireless in the 1990s (Walshok et al, 2001; Walcott, 2002; Simard, 2004; Casper, 2007).

1978 - - Hybritech founded by Ivor Royston, an asst prof. at UCSD and former Stanford postdoc, and Howard Birndorf, a lab tech, who secured backing from Kleiner, Perkins and got Brook Byers as their manager.

Developed diagnostic tests based on monoclonal antibody technology, no need for lengthy clinical trials or FDA approval, generated revenue within months of invention...one of few firms to become profitable early, had a successful IPO in 1981.

1986 - - Hybritech acquired by pharma giant Eli Lilly for $300 million and 100 million in shares. “Animal House meets the Waltons.” Huge failure!

But ex-Hybritech scientists and managers stayed in San Diego and started more than 40 biotech firms (Idec, GenProbe, Ligand, Gensia, Genta, Nanogen, Amylin, etc.) and several VC firms (Biovest, Forward Ventures, Kingsbury Partners). They partnered with scientists at the Salk Institute, Scripps, and UCSD. Bay Area VCs moved to SD. This failed merger seeded the San Diego biotech cluster.
Network evolution: Boston, Bay Area, San Diego, 6 year snapshots
Comparison of Boston, Bay Area, and San Diego:

- Different types of organizations serve as anchor tenants; each operates to foster interaction among disparate parties & provide means for local information sharing. These organizations spark the mixing of practices across domains (whatever one may think of the consequences for public science or corporate governance). No standard solution, instead a topology of the possible.

- Boston: Public Research Organizations

- Bay Area: Venture Capital, multidisciplinary model of UCSF, technology transfer at Stanford focused on relationships with startups, first-generation companies pursued invisible college model

- San Diego: Spinoffs from failed acquisition of Hybritech by Eli Lilly (“like working for your grandfather”); Salk, Scripps, & Burnham Institutes; UCSD and Connect, a university-sponsored nonprofit incubator

- In all three regions: considerable inter-org job mobility, local competitors collaborated, public & private science interwoven, all independent from overweening control of a dominant organization. Moreover, these three clusters combine dense local connectivity with extensive outside linkages.

Let’s look at the nascent clusters that didn’t take off →
Network stagnation: New York, New Jersey, Philadelphia
Network decay: 
Washington, North Carolina, Houston
Network reshuffling: Seattle and L.A.
Anchor tenant vs. 800-lb. gorilla: % of all ties by organizational form of partners, 1990, 1996, and 2002

**Type of Partner:**
- DBFs
- Fin. Institutions
- Gov't Institutes
- Pharma Corps
- Public Research Orgs
- Biomed Suppliers

For 1990, 1996, and 2002:
- Boston
- Bay Area
- San Diego
- New York
- New Jersey
- Philadelphia
- Washington-Baltimore
- Research Triangle, NC
- Houston
- Seattle
- Los Angeles
Transposition: % of local ties by organizational form of partners, 1990, 1996, and 2002

Type of Partner:
- DBFs
- Fin Institutions
- Gov't Institutes
- Pharma Corps
- Public Research Orgs
- Biomed Suppliers
Why did clusters form communities in some locales but not others?

• All of the regions had considerable local endowments, but resources alone were insufficient.

• The anchor tenants in three ‘successful’ regions catalyzed further org. and network formation, rather than acting as a hegemonic power. The norms that characterized inter-org. relations in the three clusters bore the institutional stamp of the anchors - open science, invisible college. (Relational imprinting.)

• Cross-network transposition:
  – DBFs collaborated with other local DBFs; DBF scientists published in scientific journals
  – Universities and research institutes became active in commercialization and licensing
  – VCs became executives in DBFs and donors to universities
  – Serial founders of DBFs became VCs

• In sum, in three clusters with high rates of foundings and disbandings, a self-reinforcing, mutual awareness developed into communities of common fate, with intensive mixing of practices from multiple domains that, in turn, transformed science and finance. Local density increased the speed of things bumping into each other; these became networks of transformation, not mere “pipes and prisms.”
The story is not about differential access to money: Research funding was abundant in nascent clusters
National Institutes of Health Extramural Awards, 1996, Top 50 Recipients

<table>
<thead>
<tr>
<th></th>
<th>Institution</th>
<th>City, State</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Johns Hopkins Univ</td>
<td>Baltimore, MD</td>
<td>$279,185,690.00</td>
</tr>
<tr>
<td>2</td>
<td>Univ of California San Francisco</td>
<td>San Francisco, CA</td>
<td>212,877,232.00</td>
</tr>
<tr>
<td>3</td>
<td>Univ of Washington</td>
<td>Seattle, WA</td>
<td>212,281,915.00</td>
</tr>
<tr>
<td>4</td>
<td>Univ of Pennsylvania</td>
<td>Philadelphia, PA</td>
<td>186,727,955.00</td>
</tr>
<tr>
<td>5</td>
<td>Univ of Michigan</td>
<td>Ann Arbor, MI</td>
<td>179,651,361.00</td>
</tr>
<tr>
<td>6</td>
<td>Yale Univ</td>
<td>New Haven, CT</td>
<td>174,741,782.00</td>
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<tr>
<td>7</td>
<td>Washington Univ</td>
<td>St. Louis, MO</td>
<td>172,774,071.00</td>
</tr>
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<td>8</td>
<td>Harvard Univ</td>
<td>Cambridge, MA</td>
<td>166,727,904.00</td>
</tr>
<tr>
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<td>Scripps Research Institute</td>
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**KEY:** **BLUE**: established clusters  **GREEN**: nascent clusters  **BLACK**: other locales
<table>
<thead>
<tr>
<th>No.</th>
<th>Organization</th>
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</table>

**KEY:**
- **BLUE:** established clusters
- **GREEN:** nascent clusters
- **BLACK:** other locales

Location of DBF:
- Local Cluster
- Major US Clusters
- Minor US Clusters
- Other Locations
How do fields evolve and change?

- Starting points and sequences matter - what types of organizations are involved and where you begin shapes where you can go. Local ties embody a firm’s initial core knowledge and form its social capital base. Distant ties reflect cosmopolitan status, but when they come first, they hinder building a local cluster. *(A process story not a recipe!)*

- Windows of opening can be brief - locational opportunities are ephemeral in science-based fields, and institutionalization may depend on catalyzing those ingredients at specific moments. *(This is not a linear story!)*

- Multiple logics always present - but how you work, whom you work with, and what you work on are conditioned by micro patterns of partner choice and local norms that sustain the evolving field structure. Particular types of ties (R&D) can be repurposed in ways that others cannot.

- Multivocality - actions can be interpreted from diverse perspectives simultaneously; multivocal actions are moves in multiple games at once.

- Change does not necessarily entail uprooting of incumbents and replacement by challengers. Elements of the old guard may find new tools to retain position, or forge alliances with new entrants, or co-opt them. Multiple network transposition does insure reshuffling of relations and identities, and altering of criteria of evaluation. For example, Pharma corps. move R&D labs to Kendall Square and La Jolla; Novartis creates nonprofit Genomic Institute in La Jolla; Harvard endowment fund invests as VC, VCs begin entrepreneur in residence programs.
Conclusion:

• Relational density and transposition foster multiple criteria for evaluation, offering catalytic possibilities that no broker or strategic actor could ever anticipate. Cross-network transposition was the means by which ideas and skills were transferred into new domains, and put to novel purposes. Such cascades are unusual, but when they occur and are reinforced by multi-connected organizations, the potential for institutional change is considerable.

• Diversely anchored, multi-connected networks are much less likely to unravel than networks reliant on a few elite organizations, and the organizing practices of such networks are more likely to become institutionalized.
Chapter 15: An Open Elite
Arbiters, Catalysts or Gatekeepers in Industry Evolution?
Walter W. Powell       Jason Owen-Smith
Amphibious entrepreneurs created science-based companies, largely out of naiveté, forging and repurposing practices of science and finance.

These firms in business to do science, the VCs who funded them, and the nonprofit (but commercially engaged) research institutes they worked with became anchor tenants of three robust regional clusters.

How do highly central organizations retain their position in an expanding global field in which scientific discovery and commercial competition are intense?

Put differently, when knowledge is advancing rapidly and is geographically dispersed, networks become the locus of innovation. But what factors enable densely connected networks to avoid lock-in and ossification? The aim of this chapter is to explain industrial dynamics of simultaneous expansion and contraction.
Continuous innovation, rapidly developing scientific base, high rates of R&D failure, over-reliance on blockbuster drugs by big pharma, strong regulatory and IP environment, fluid labor markets, unusual mix of very large and small firms, nonprofit and government institutes and universities, new forms of venture financing tied to fads in equity market, customer attachment to treatments, not producers.

Expert opinion and canonical theory is divided as to how to explain this industry’s evolution:

- Cockburn and Stern (2010), Kleinman and Vallas (2006): Remaking of insular world of big Pharma, and entrepreneurial university science lead to hybrid model of partially open, IP-protected science (gales of creative destruction - - a recombination story)

- Pisano (2006), Nightingale and Martin (2004), Coriat et al (2003): The dominant process is the outsourcing of upstream R&D to biotech firms and universities, with Pharma companies reaping the lion’s share of advantage. (Chandlerian story or neoliberal project of lean and mean).
Industries can be conceived of as relational fields - configurations of relationships and communities of diverse organizations, engaged in common activities subject to similar pressures. Networks are the skeletons of fields. The most central organizations in a field are its backbone.

New tie formation by core organizations is the motor of field evolution (Powell et al, 2005). The affiliation networks of organizations not only mark past experiences but are a road map of future prospects.

The organizing principles of complex systems are encoded in their network topologies. The logics of preferential attachment vary depending on which activities are being conducted with whom.
How should we think about an elite in network terms?

- A small number of organizations who dominate the majority of affiliations. This highly influential group can be either closed or permeable.

- To analyze this idea, we use K-cores – concentric circles reflecting increasing relational density.

- The most connected k-core is a highly cohesive cluster

- Does such a structural elite have self-awareness?
  - in a class solidarity sense NO
  - in terms of oligarchic interests PERHAPS
  - with regard to status endogamy YES
Elite ties serve multiple purposes. New connections can...

• **Protect existing status** - Elites form multiple, non-redundant ties with other well-connected participants. We term these *conserving ties* as they are new partnerships with organizations of similar high connectivity. Such affiliations stabilize the power of the best-connected, at the risk of lock-in.

• **Prospect for novelty** - Elites form new ties with outsiders (overwhelmingly new entrants and young organizations) who have no prior ties to other members of the elite. This search for novelty represents an *expansion tie*. These linkages afford access to new ideas, at the risk of upsetting the status order.

• **Validate up and comers** - An additional tie is forged between another member of the elite and a new entrant. We term these *closure ties* because they mark the outsider as a promising prospect. Over time, ties to additional members of the elite can pull the prospect into the inner circle. These closure ties reflect sponsored mobility.
Data and Methods:

- Same relational data set as previous chapter, extended to cover 1984-2004 and global affiliations, not just U.S. A two-mode network: 691 biotech firms, 3,000 plus collaborators, 15,197 relationships.

- To identify the most connected members of the network, we use the method of k-core decomposition (White and Harary, 2001; Moody and White, 2003). Conceives of the architecture of a network as a set of successively enclosed substructures. Used to study protein interactions, friendship cliques, kinship lineages, disease transmission.

- Put simply, a k-core decomposition is like peeling an onion layer by layer, revealing the structure from the outmost skin to the inner bulb. By peeling away the least connected members of the field, we can determine who the most connected, cohesive members are.
The Database: Ties


<table>
<thead>
<tr>
<th>Type of Tie</th>
<th>Typical Partners</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>R&amp;D:</strong> Biotech firm develops research program with another organization for a specific target.</td>
<td>Other biotechs, pharmaceutical corps., universities, research institutes, government labs.</td>
</tr>
<tr>
<td><strong>Finance:</strong> Partner invests funds in a DBF, or DBF invests funds (and scientific expertise) in a partner.</td>
<td>Venture capital firms, larger biotech companies, pharmaceutical corp.</td>
</tr>
<tr>
<td><strong>Licensing:</strong> DBF either licenses its intellectual property (IP) to another party, or acquires others’ IP.</td>
<td>Universities, Research Institutes, DBFs, pharmaceuticals, govt. labs.</td>
</tr>
<tr>
<td><strong>Commercialization:</strong> DBF contracts with partner to manufacture and market its product, or DBF agrees to supply product to a distributor for sales.</td>
<td>Large pharmaceutical or chemical corps., larger DBFs</td>
</tr>
</tbody>
</table>
What to look for in a k-core visualization

- Present a fast network movie - 4 snapshots of the most connected component of organizations.
- What to watch for:
  - How does character of relations change from time? Both form and content, i.e., organizations and activities.
  - How do position and structure co-evolve? Who is at the center and does overall composition shrink, expand, or re-shuffle?
- Not shown, but trust us!:
  - Analysis of tie formation in terms of characteristics of new tie participants.
Main component, 2 core, 1984

Dominant activity is the selling by early biotechs of their lead molecules to pharma companies.
Main component, 4 core, 1990 (4 or more nonredundant ties with one another)

Growing salience of finance (entry of VCs) and science (entry of universities, centrality of NIH) affiliations. Composition shifts to centrality of first generation DBFs.
Main component, 5 core, 1996

Number of members and affiliations grows markedly.

Financial relations supplant commercial ties. VCs and pharma offer different modes of financial support. (Recall contrast of in science to do business vs. in business to do science.)
Main component, 5 core, 2002

Science and finance ties at the center; re-entry of select pharma corps. under new logic of attachment.
Results:

- Elite expansion is notable (no pulling up ladders), reflects entry of venture capital, maturation of biotech firms, increased involvement of top-tier universities and institutes.
- Sponsorship involves drawing recognizable new entrants into the club, not assisting friends of inner circle. In technical terms, triadic closure is uncommon; prospecting more likely.
- Shifting logics of attachment preclude formation of an oligarchy. Most frequent relationships move from commercial to financial to scientific. Elite members use prospecting as a means to retain centrality as they learn new capabilities.
- Staying on top is hard work. Elite position affords both influence and opportunity. **Running faster to stay in place** - searching, fending off and acquiring rivals, and adapting to new skills. The ‘game’ involves ceding control over one form of power and garnering support to develop new tools of influence.
- Structurally, organizations of a similar form and comparable connectivity compete with one another; those of different form and level of connectivity collaborate.
Implications:

- The mantra of our book is: in the short run, *actors make relations* but in the long run, *relations make actors*.

- The narrative we have told is one where the tools of everyday practice were used in unfamiliar circumstances at a time when there was a green field. As norms of science spread into commercial biomedicine, new forms of collaboration and modes of financing medical discovery developed, giving rise to robust, but highly select, industrial districts. Key participants outside those clusters had to engage with them, but on their terms. A densely connected, global elite formed that was open to promising newcomers, not out of generosity but in order to retain central position.
CHAPTER 16: ACADEMIC LABORATORIES AND THE REPRODUCTION OF PROPRIETARY SCIENCE: MODELING ORGANIZATIONAL RULES THROUGH AUTOCATALYTIC NETWORKS*

Jeannette A. Colyvas       Spiro Maroulis

*Support for this project came from the Northwestern University Research Grants Committee, the National Science Foundation (#0849036), and the Center for Connected Learning and Computer-Based Modeling.
The introduction to this volume emphasizes the origins and emergence of new forms as a collective blind spot in the social sciences.

Few analysis capture the relationship among all three features of social and economic life—the origin of new practices, their emergence as broader self-reproducing structures, and the form that they take as a result of this process.

Our approach to this question examines how disparate elements of the social organization of academic science were assembled, transposed, and recombined to define a new regime of public and proprietary science.

We combine detailed archival analysis with computational agent-based modeling to examine the introduction and adoption of proprietary science in the academy, specifically as a set of routines that shaped the production and disclosure of university-based research.

We emphasize the transformative aspect of self-reinforcing processes in recasting networks, shaping organizational routines, and potentially guiding science.
One of the most salient transformations that has taken place in recent decades is the introduction and spread of commercial practices in the academy, particularly in the form of patenting.

Technology transfer was initially unfamiliar to universities and scientists, but eventually became legitimate and expected.

Many argue that this change reflects the mixing of once disparate domains of public (university) and proprietary (industry) science.

- The nature of the goals accepted as legitimate
- Features of the reward system
- Norms of disclosure

The adoption of patenting by academic scientists, initially in the 1970’s and in greater force in the 1990’s, reflected a contrasting norm of disclosure.

- It conferred the right to exclude others from using a research finding and
- It permitted scientists and universities to make money from those findings.
From our perspective, understanding this transformation requires

- situating practices in the social and organizational system of academic science,

- and recognizing how the features that give rise to an institution can be different than those that reinforce it once in place.
OUR ANALYSIS

- Our aim is to illuminate the feedback dynamics of crossing boundaries and emergent institutional change.

- As the “amphibious” life scientists described in previous chapters came into contact with the world of commerce, how did their experiences reverberate into the conservative halls of academia? How were commercial practices, like patenting adopted, and in what form?

- We explain this process through the recombination of meanings and practices within the existing social structure of science.

- We also demonstrate how patenting practices originated in labs, rather than through policy incentives or regulative controls.

- We demonstrate how scientists’ efforts to maintain autonomy and expand the reach of one’s research program fueled change, despite the fact that these actions were part of concerted struggles to preserve the academic system.

- Our analysis shows that efforts to operate within the social structure of science generated the mechanisms that transformed it.
Emergence is a bottom up process as repeated social interactions give rise to vocabularies of motives that come to define what is standard and appropriate.

New forms are built by participants situated in the cultural routines of their past.

Opportunities and constraints, both new and old, make some participants receptive to alternatives from other domains, which remain invisible to others.

When transposition happens, new practices are assembled selectively rather than adopted wholesale, and as they become integrated into the social order, these practices can also alter the domain in which they are transposed.

Emergence is built on scaffolding of networks that transform rather than transmit.
### DATA AND METHODS

#### Archives
- Administrative and invention records of Stanford University
- Focus on life science invention disclosures 1968-1982
- 42 inventions linked to a basic life science department, classified by lab, inductively examined points of intersection between commerce & academia

#### ABM*
- Advantage of clarity in forcing a precise translation of qualitative findings into “runnable” code
- Providing a platform to explore counterfactuals that are otherwise impossible to investigate

#### Process
- Begin with core question about the emergence of proprietary science
- Derive insights from the archives
- Translate insights to ABM
- Conduct controlled tests of mechanisms that can explain our outcome

*ABM developed using NetLogo, Wilensky 1999.*
**Example of Coding Scheme for Invention Disclosures by Lab**

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<tr>
<th>Laboratories and Research Agendas</th>
<th>Organizational and Legal Dimensions</th>
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<tbody>
<tr>
<td><strong>Lab Model:</strong></td>
<td><strong>Invention</strong></td>
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<tr>
<td><strong>Practices</strong></td>
<td><em>What kinds of science constituted an invention</em></td>
</tr>
<tr>
<td></td>
<td><em>e.g. patent anything commercializeable, patent only devices not basic research</em></td>
</tr>
<tr>
<td></td>
<td><strong>Inventor</strong></td>
</tr>
<tr>
<td></td>
<td><em>Who was an inventor</em></td>
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<tr>
<td></td>
<td><em>e.g. list technicians only, include main co-authors, or PI's only</em></td>
</tr>
<tr>
<td></td>
<td><strong>Revenues &amp; Rewards</strong></td>
</tr>
<tr>
<td></td>
<td><em>How revenues would be disbursed</em></td>
</tr>
<tr>
<td></td>
<td><em>e.g. share with co-authors, donate, turn over to the lab</em></td>
</tr>
<tr>
<td></td>
<td><strong>Boundaries btwn. Science &amp; Business</strong></td>
</tr>
<tr>
<td></td>
<td><em>The degree/form of engagement in tech transfer process</em></td>
</tr>
<tr>
<td></td>
<td><em>e.g. &quot;hands-on&quot; or &quot;hands-off&quot; in all aspects, or specific partitions</em></td>
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<td><em>The rationales, premises or definitions articulated as inventions</em></td>
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<tr>
<td></td>
<td><em>The rationales, premises or definitions articulated as inventors</em></td>
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<tr>
<td></td>
<td><em>The rationales provided for particular arrangements</em></td>
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<tr>
<td></td>
<td><em>The rationales provided for the degree or form of engagement in business or why some boundaries while not others</em></td>
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**Theoretical and Empirical Claims**

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<th>Characterizing the Knowledge Production Process</th>
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<tbody>
<tr>
<td>• Science is based on cumulative production of knowledge &amp; relies on distributed skills.</td>
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<tr>
<td>• Lab success relies on others using the science they produce.</td>
</tr>
<tr>
<td>• Labs reproduced their practices by training doctoral graduates.</td>
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<table>
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<tr>
<th>Characterizing the Adaptation of Labs</th>
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<tbody>
<tr>
<td>• Scientists learned from others patenting downstream developments of their work.</td>
</tr>
<tr>
<td>• Scientists reacted to patenting among peers.</td>
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</table>

<table>
<thead>
<tr>
<th>Characterizing Forms of Disclosure</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Commerce developed in labs, linking opportunities to change &amp; to produce</td>
</tr>
<tr>
<td>• Patenting was contingent, depended on findings, &amp; could change at each disclosure.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Operationalization in the Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>• <strong>Scientific production routine</strong>: labs are comprised of skills that transform scientific products.</td>
</tr>
<tr>
<td>• Lab survival depends on having skills that are replicated when knowledge advanced to another lab.</td>
</tr>
<tr>
<td>• Each lab is given a <strong>reproduction routine</strong> where new labs are &quot;hatched&quot; with some random mutation.</td>
</tr>
<tr>
<td>• <strong>Knowledge disclosure routine</strong> activated by the knowledge production process.</td>
</tr>
<tr>
<td>• Labs have different <strong>patenting thresholds</strong> &amp; products have different <strong>science value</strong> (1-100).</td>
</tr>
<tr>
<td>• <strong>Participatory adaptation routine</strong>: labs update PT as weighted avr. of their’s &amp; successful colleagues’.</td>
</tr>
<tr>
<td>• <strong>Preemptive adaptation routine</strong>: labs update PT based on the existence of more liberal colleagues.</td>
</tr>
</tbody>
</table>
INSIGHTS FROM THE ARCHIVES

- Despite extensive scholarship emphasizing national and local incentives, approaches toward commercializing research emanated more from labs than government, legal, or university sources.

- Variation in approaches and rationales for commercializing:
  - Threshold of what was patentable
  - Distribution of potential resources given back to science
  - Debates hinged on control over science & the ability to direct the resources rather than appropriate them personally.

- Engagement in commercial science was shaped by the production process and reward system of science.

- Approaches in labs were not fixed, but changed over time.

- These observations prompted us to think about the emergence of proprietary science as the shift in a threshold from few to many adopters; and willingness to patent few things to mostly anything.
“Although many of us are not in a position to exploit our discoveries, we do feel that universities and university-based research should benefit from profitable applications of our findings. I had hoped that an industry so recently spawned by university research would be enlightened in its recognition of who is responsible for its existence....Your comments leave me and other[s] no alternative but...to patent or make exclusive arrangements for whatever we develop. I can assure you that I will alert my colleagues throughout the world to guard against what I consider exploitation...”
“…It is not infrequent that inventors will...forego their personal share...There is a strong feeling by many, if not most inventors, that as they are responsible for bringing in the royalty funds, they should have a strong (if not the only) voice in controlling distribution of income...A royalty income fund under control of a PI would allow the PI to get a piece of equipment for general laboratory use, to send people to important technical society meetings for which grant or other funds are not available, etc...”
“I can accept a view that it is more reasonable for any financial benefits derived from this kind of scientific research carried out at a non-profit university with public funds to go to the university, rather than be treated as a windfall profit to be enjoyed by profit-motivated... [organizations]; I agreed to cooperate with Stanford for that reason... [but]...on the understanding that it would be made perfectly clear to all concerned that I would receive no personal gain from the patent.”
MECHANISMS

- Guided by the experiences of the observed labs, we included three mechanisms that explained the emergence of proprietary science.

  - **Lab Reproduction**: a means of population-level learning that reflected a key way in which the social structure of science is reproduced, which in turn can play a role in emergence. This mechanism was also inspired by the instrumental role of graduate students and postdocs as they left their advisors to establish their own labs.

  - **Participatory Adaptation**: a means of social influence that incorporated the ways in which scientists’ engagement in transferring their knowledge to more commercially-minded partners prompted the rethinking of their practices.

  - **Preemptive Adaptation**: a form of adaptation for scientists that captured the ways in which the prospect of others patenting, and incurring the right to exclude others from further developing their area of science, provoked them to take up patenting themselves.
We drew on these insights to develop an agent-based model to examine the shift from a few labs willing to patent a narrow range of findings to most labs willing to patent a broad range of findings.

From an ABM perspective, we characterized the emergence of this activity as a reference pattern representing this shift in a patent threshold distribution.
DESCRIPTION OF THE MODEL

- Our model is made up of three parts: scientific products, skills, and scientific labs.

- Scientific labs use skills to transform scientific products.

  $1 \rightarrow 2 \rightarrow 3 \rightarrow 4 \rightarrow 1$

- Following Padgett’s chemistry-inspired model, this transformation process can result in self-reinforcing chains of production. This is the evolutionary engine.

- Labs are rewarded when using skills in a successful transaction by the replication of their skills.

- We layered a process of patenting on top of this production: scientific labs also own decision-making routines that determine whether to patent.

*Padgett, 1997; Padgett, Doowan, and Collier, 2003; Padgett, McMahan, and Zhong, 2009*
EXPLAINING REWARDS IN THE MODEL

- Scientific products represented as balls sitting in an urn with three attributes
  - **Type**, indicated by a number 1 to n.
  - **Scientific Value**, indicated by a number 1-100.
  - **Patent Status**, indicated by whether or not it is patented in a transaction.

- Labs are arrayed spatially on a grid with wrap-around borders, and connected to each other via collegial ties (i.e. Moore neighborhood).

- Labs are rewarded based on relative benefit in successful transactions.
  - In successful **publication-publication** transactions, the sender’s knowledge advancement routine is duplicated.
  - In successful **publication-patent** and **patent-publication** transactions, the receiver’s knowledge advancement routine is duplicated.
  - In successful **patent-patent** transactions, both the sender’s and receiver’s knowledge advancement routines are duplicated.
CHANGE ROUTINES IN THE MODEL

- Labs can adapt
  - **Reproduction**: specifies the patentability threshold of the offspring, with an exogenously determined parameter that governs the amount of random mutation; also specifies the likelihood that the offspring will inherit any given link to a parent’s network, including the parent themselves.

  - **Participatory Adaptation**: lab updates its patent threshold when it’s transaction partner was rewarded more than they were; recalculated as the weighted average of its current threshold and the threshold of the more successful transaction partner.

  - **Preemptive Adaptation**: lab updates its patent threshold if a lab has a network neighbor whose disclosure routine would lead to the patenting of the product; adjusts its patent threshold to the minimum level that allows it to patent the product itself.

- Labs can die (when they run out of skills)
  - When a routine is duplicated, another routine chosen at random is killed off.
A “DAY” IN THE LIFE OF A LAB

* Knowledge advancement routine
  chosen at random
  "ready for action"

* Labs with scientific product
  apply preemptive adaptation
  routine: Is there a network
  neighbor who would be willing
  to patent this kind of product?

  * Keep the lab's patentability
    threshold the same

  * Return scientific product to um

  * Labs with scientific product
    apply knowledge advancement
    routine: Does this lab have the
    skills to transform the idea?

  * Apply disclosure
    routine: Is this scientific
    product something the lab is willing to patent?

    * Produce Knowledge
      Published not patented

    * Transform product into
      new scientific product
    * Pass product to neighbor

    * Produce Knowledge
      Patented and published

    * Transform product into
      new scientific product
    * Pass product to neighbor

  * Labs apply their participatory
    adaptation routine: Did the
    receiver get the relative reward
    in this transaction?

    * Keep the lab's patentability
      threshold the same

    * Update the lab's patentability
      threshold

* dotted lines represent adaptation routines that can be turned on or off.
EVOLUTION OF AGENT-BASED MODEL OVER TIME
MULTILEVEL SCIENTIFIC PRODUCTION NETWORKS

Figure 16.3 Multilevel scientific production networks. A. Social network. B. Skill level scientific production network.
TRANSACTION TYPES OVER TIME

A. Transaction Types Over Time with Preemptive Adaptation On

B. Transaction Types Over Time with Preemptive Adaptation Off
CHANGE ROUTINES

B. Final Time Period

Even Reward Structure

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Favor Patents Reward Structure

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Favor Publications Reward Structure
INSIGHTS FROM THE MODEL

- Even when the environment favors publishing over patenting, the preemptive adaptation mechanism can lead to the shift in the patent threshold distribution.

- Small, incremental adjustments at the level of labs and at individual instantiations of scientific findings can lead to a dramatic change. You really just need neighbors that are slightly different from you.

- This finding compliments accounts of the expansion of patenting activity and provides one instantiation of how the features that give rise to commercializing science are different than those that support them once settled.

- By adapting the autocatalysis framework to the setting of proprietary science, we extend an existing model of the emergence of economic “life” to the emergence of disclosure regimes that govern the production of knowledge.

- We demonstrate accommodations to the model to address the production of science.
INSIGHTS INTO PROPRIETARY SCIENCE

- By examining life scientists at the origins of patenting, we demonstrate how commercializing academic science was a contingent and relational decision and not only a matter of whether scientists willing to accept the practice of patenting in their labs.

- Inventions that culminated into patents were the result of multiple factors: the process by which scientists conducted their work, their perceptions about appropriate ways to relate to colleagues in both universities and firms, and particular research findings under consideration.

- Debates emerged at point of contradiction between science and commerce, prompting seemingly similar problems of control over resources and organizational survival despite different rationales.
Even without centralized control—such as external laws or policies—we demonstrate ways proprietary science can emerge, without top-down coordination or control.

Moreover, we demonstrate the difficulty in achieving this through basic processes of selection and reproduction.

Stated differently, in order to get self-reinforcement and reproduction of new routines, labs have to interact and be willing to change their rules and conceptions about invention.