Venture Capital
and the Economics of Innovation

Lecture 6

Exploring New Economic Space

"Profits of Doom"

"**Let is now praise famous men, the wild-eyed enthusiasts who begat the bubble-boom**. When the stock market hit the puke stage, conventional wisdom turned. The whole new economy thing had been a bad thing. Time, talent, and capital were thrown away on unsustainable enterprises like point-and-click pet food….

"Conventional wisdom…once rode side by side with the prophets of change.

"**Today's party line is that the gold rush brought both pain and gain**. Fortunes were poured into overflowing snake pits of fiber-optic cables, which, like Web-ordered groceries, proved to be profit-free zones. In just four years, the craze sucked up $600 billion of purchasing power….On the flip side, public markets paid for a build-out of the network infrastructure, and burn rates pushed the envelope of the culture at large….

(B. DeLong, "Profits of Doom," *Wired,* 11(4) (April 2001), p. 1)

Social Returns *versus* Profits of Firms

“**In fact, history will look back and see gain and gain**. That’s because profits are not the same thing as social value. Just because a group of firms, an industry segment, flopped as a profitmaker does not mean it failed as a producer. Profit is primarily a signal about the size of a set of enterprises…. If profits are high, the industry segment should grow; if absent, it should shrink.

“**That the dotcom and telecom sectors needed…to shrink has next to nothing to do with how useful their products will turn out to be….British investors in US railroads during the late 19th century got their pockets picked twice**: first as waves of overenthusiasm led to overbuilding, ruinous competition and unbelievable…burn rates, and second as sharp financial operators stripped investors of control and ownership during bankruptcy workouts. **Yet Americans and the American economy benefited enormously from the resulting network of railroad tracks that stretched from sea to shining sea**…

(DeLong, p. 1)

The “Killer App” of the Railroads

“[A] curious thing happened as railroad bankruptcies and price wars put steady downward pressure pm shipping prices and slashed rail freight and passenger rates across the country: **New industries sprang up**.

“Consider…the old **Montgomery Ward and Sears Roebuck catalogs**….Mail a catalog to every household in the country. Offer the big-city goods at near big-city discounts. Rake in the money from satisfied customers. **For two generations this business model—call it the ‘railroad services’ business model—was a license to print money, made possible only by the gross overbuilding of railroads, the resulting collapse of freight rates, and the fact that railroad investors had had to kiss nearly all their money good-bye**….

“**The same thing will happen with the froth that the bubble put on our 1990s boom. Investors lost their money. We now get to use all their stuff**….”

(DeLong, pp. 1-2)

Electrifying America: By Experimentation

"…**Muncie…experimented with direct and alternating current, with Edison lamps and Brush arc lights, with gas and electrical lighting, with steam 'dummy' trains and electric trolleys, with district heating, with metered and unmetered service, and with both public and private utility ownership. The experiments and the final choices were typical for the country as a whole.** The chronology of Muncie's acquisition of services was also typical. Electricity appeared in public places and in handful of well-to-do mansions in the 1880s, but most houses were not wired until after 1915….The streetcar, despite great popularity in the 1890s, disappeared in 1931, while the interurbans survived longer. **The impact of electricity on industry did not come until after 1905, but was much more lasting**. Muncie was also typical in its rapid acquisition of appliances after World War I, in its rejection of government ownership of utilities, and in the eventual need for government intervention to bring electricity to farmers."

(J. Nye, *Electrifying America: Social Meaning of a New Technology* (Cambridge MA, MIT Press, 1992), pp. 26-7)

“General Purpose Technology”: Three-part Definition

“…a basic definition of GPTs with three parts: **a GPT (1) is widely used, (2) is capable of ongoing technical improvement and (3) enables innovation in application sectors (AS). The combination of assumptions (2) and (3) is called “innovation complementarities” (IC)**.

“More precisely, IC means that innovations in the GPT raise the return to innovations in each AS and *vice versa*….What is important here is that the social increasing returns to scale (SIRS) arise across the entire *cluster* of technical change in the GPT and technical change in the AS.

“…**Like many models of innovation, a GPT cluster can overcome diminishing returns because innovation is inherently an increasing return activity**. Obviously, if a GPT has economy-wide scope, the relevant increasing returns also matter at the aggregate level. **Less obviously, a GPT can trigger sustained innovation over a period of time because of the positive feedback between the GPT and the AS**.”

(T. Bresnehan, “General Purpose Technologies,” in B. H. Hall and N. Rosenberg (eds.) *Handbook of the Economics of Innovation,* 2 vols. (Amsterdam: North Holland, 2010) vol 2., pp. 764-5)

Segmentation of GPT by AS

“**…[A]n MRI machine and an accounting system have a common input, computing**. They have different optimal specifications in their derived demand for this input—even after we take into account the co-invention effort. Scientific and engineering applications of computers, like MRI machines, typically have optimal specifications involving an inexpensive computer which can perform numerical calculations effectively. Business data processing applications, in contrast, have optimal specifications that put significantly more weight on reliability, large-scale data input/output operations, fail-safe maintenance of databases, and so on.

“**This diversity has been met in the computer industry by market segmentation**….This market segmentation involves a limitation on sharing technical inputs. It also creates partially separate, partially overlapping positive feedback loops. …For now the point is that **the model in which there is ‘a’ GPT and it is seamlessly used in all the sectors and subprocesses of an economy needs to be thought through carefully.**” (Bresnehan, p. 769)

Alternative Links between GPT and AS

“**The basic GPT structure could be mapped into goods and markets in any of a number of ways. The GPT could be disembodied knowledge** (…the factory system or mass production), **or it could be embodied in a good or service** that is purchased by the applications sectors (…computing). **If it is embodied in a capital good, that good could by bought by the applications sectors** (like a computer or an electric motor), or, **alternatively, services of that capital good could be sold by a GPT firm to each AS** (like railroad tracks). The GPT can be in the public domain, controlled by a single firm with a patent or trade secret, or supplied by a large number of different firms each of which has distinct versions. The same set of alternatives applies to the AS….

“**There is a parallel question of timing of investment**. Consider the difference between a railroad and a steam engine. A railroad line must be invested in before any customers can be served; the corresponding investment in a steam engine occurs on a customer-by-customer basis….”

(Bresnehan, p. 765)

Steam Power: The Prototypical GPT

“Steam is the prototypical GPT and the history of steam suggests a number of complexities for us to consider. **The first point is that steam power took a very long while to diffuse across application sectors**. Starting from the eighteenth century, steam was first important in mining and then in textile manufacturing. **Yet even a century and a half after the first production use of steam, steam still did not provide the majority of power used in textile manufacturing**. Steam power diffused in other manufacturing industries yet more slowly. Steam was used in transportation (especially in ships and in railroads). As in manufacturing, the within-sector diffusion in transportation was along slow process. Steam-powered ships replaced some sailing ships quickly, notably in uses where wind was unreliable or reliability was extremely valuable, but **sailing ships persisted in other uses into the twentieth century**.” (Bresnehan, p. 770)

Steam and Coal:
General Equilibrium Effects

"**Steam power is in a particularly interesting relationship to coal, and one that illustrates a general point**. It is at once true that coal is a fuel for steam engines and that early steam power was particularly important in the mining of coal. **The dependence of coal on steam and of steam on coal immediately suggests the importance of a general equilibrium analysis in which technical and market advance in coal and in steam engines** are jointly determined. **Given that the basic idea of a GPT bridges from the analysis of technology to the analysis of society's growth needs, one should of course expect general equilibrium effects**…."

(Bresnehan, p. 771)

Slow Diffusion of Steam: Supply Constraints

“**Early steam power had profound limitations. It could not provide continuous rotary motion**, for example. This thwarted applications where mechanization was central. After at least two major improvements in the steam engine (from Newcomen and Watt), rotary power was at last possible. **A second limitation of early steam power was the problem of process control**. Until steam power could provide power that could be predicted, stable and steady, that is controlled, it would be unsuitable for applications that could not use jerky or otherwise unreliable power. The invention of the Corliss steam engine and its ongoing improvements provided much more controlled steam engines….

“**Improvements in steam power involved a wide range of different ‘technologies’ in the engineering sense**, that is , a wide range of different bodies of knowledge**….[T]he economic incentive to supply and improve the complementary inputs to the steam engine itself was at work for a long period before the steam engine had suitable features to enable a wide range of innovations in complementary activities**.”

(Bresnehan, p. 770)

GPTs and Heterogeneous Economic Sectors

"**The basic assumption which makes GPT analysis interesting is that all of the different sectors of the economy, and all the different subprocesses within the production process in each sector, are quite heterogeneous**. Diagnosing brain tumors and tracking/collecting accounts receivable, for example, are extremely different production subprocesses important in vastly different sectors of the economy. **The innovation cost function of a large, heterogeneous economy can be lowered in the aggregate if there is a mechanism to share the fruits of innovative effort across some of these diverse sectors and subprocesses**. The diagnosis and accounting example…illustrates how technical progress in computing would, if combined with co-invention in medicine and in finance, be spread across a wide number of sectors….More generally, GPT models assume that specific intermediate inputs can be made very cheap through continued technical advance and that those are easily made useful in a wide variety of sectors and subprocesses….**The GPT structure creates a wide scope of applications for GPT innovations, and thus a large level of social increasing returns, by using AS co-invention to avoid…diminishing returns**."

(Bresnehan. P. 767)

Externalities

"While an increase in T_G gives an incentive to AS inventors to increase their innovative efforts, they pick $\dot{T}_a$ to maximize $\lambda \dot{V}_a$. If they were maximizing all of producer returns, they would pick an even higher level of $\dot{T}_a$ that would maximize $(\lambda_a+\lambda_G)\dot{V}_a$. **This external effect is above and beyond the spillouts to consumers not internalized by investors** (which the GPT literature treats as an unavoidable cost of invention).

"**This externality is symmetric**. Consider the private returns to inventors in the GPT….**A higher rate of technical progress in any a sector, T_a, increases both private return to the innovator in G and the marginal return to increases in T_G (because of IC).** So the symmetrical result holds: **there is the positive prediction that increases in any T_a will causally lead innovators in the GPT to increase T_G. There is also the external effect. The increase in T_G…is less than the amount which would maximize producers' returns for all producers as a group**."

(Bresnehan, p. 767)

GPT Theory: SIRS and Externalities

"The basic GPT structure implies three general results, SIRS in economy-wide invention and the two external effects. **The social increasing returns stem from the superadditivity between inventive effort in the GPT and inventive effort in the applications sectors.** There will be a high social rate of return to success at coordinating technical progress in the GPT with technical progress in a large number of applications sectors. As is true of any model with social increasing returns, however, there are external effects. Given the particular structure of [the] basic GPT model, **there are two external effects**. There is a **'horizontal' external effect across application sectors (each application sector would like other applications sectors to invest more than is in their independent interest)** and a **'vertical' external effect (increases in the economic return to GPT invention at the margin imply either social waste or decreases in the return to AS invention)**.

(Bresnehan, pp. 767-8)

Coordination Issues

“**…[T]he external effects and the SIRS associated with a GPT do not turn on it having an economy-wide scope**. If there are a substantial number of different applications sectors, but not all the economy, there can still be considerable SIRS from sharing a common input. Similarly, the problems associated with successfully achieving coordination (incentives or information for technical forecasting) would be the same even if the scope were less than economy wide.

“…**Absent coordination among a GPT and a number of AS, the private return to innovation in either area fall[s] short of the social returns because of the two external effects**…Better coordination leads to a positive feedback loop in which innovations in either AS or GPT raise the private incentives to innovate elsewhere in the system. **The implications…drive the results that a GPT positive feedback loop may be slow or difficult to start but valuable once it begins**.” (Bresnehan, p. 768)

GPT Improvements and New AS

"**The nature of the improvements in steam power that loosened the supply constraint on diffusion brings us to another general point about technical progress and thus about GPTs**. These improvements…did not merely take the form of lower costs for an existing set of product characteristics. Instead, **the available range of steam engine product characteristics widened**….Improvements in product characteristics generally are an important source of value creation in technical progress. This is especially the case when the **improvements…create either the opportunity for or the incentive for complementary innovations**. The important distinction between improvements in cost and improvements in those product characteristics which are not like cost applies to GPTs as well."

(Bresnehan, p. 771)

Finding Markets for GPTs

“[Helpmans’s and Trajtenberg’s] theory allows for a number of different effects, including the **aggregate demand** (willingness to pay times market size) in an AS, the **immediate benefit** of the GPT relative to the technologies in use in the AS, **development costs** in the AS per needed additional innovation and the **number (scope or complexity) of complementary components** which would need to be innovated in the AS….

“The conclusion…is that **sectoral pattern of early adoption of semiconductors was driven, not by tradeoffs among the four factors…but by the existence of a few sectors (such as hearing aids) in which all four factors were very favorable.** Perhaps more interesting, the laggard sectors (such as automobiles or telecommunications) they characterize as strongly determined by the number…of complementary innovations which would be needed to incorporate the new GPT.”

(Bresnehan, p. 779)

SEE: E. Helpman, and Trajtenberg, M. “A Time to Sow and A Time to Reap: Growth Based on General Purpose Technologies” in E. Helpman (ed.) *General Purpose Technologies and Economic Growth* (MIT Press:1998).

Forecast Errors

"…[W]hile Helpman and Trajtenberg have a formal model with perfect information,…**they are not afraid to examine the 'forecast errors'** which led early observers to see certain applications sectors as likely demanders of the GPT. **The forecast errors they identify focus on the potential benefits of the GPT in the AS, underestimating the size and complexity of the co-invention needed to make a successful adoption**. They note as a historical accident that, while AT&T's development of the semiconductor for telecom uses involved a 'forecast error,' there was also a 'historical accident' that linked Bell to hearing aids. The general analytical point, which has not been deeply analyzed in GPT models, is that **at the beginning there can be very limited information about the applications of a potential GPT among technologists and about the value of using a potential GPT among applications sectors.**" (Bresnehan, p. 780)

New and Old GPTs: Complementarities

“…[T]he preexisting technologies may have complementary inventions in some or all of the potential applications sector for a new GPT. These may be sunk investments, or the old AS invention may be portable to the new GPT. In the case of steam, portability of some preexisting complementary investments showed an element of dynamic complementarity….**We can see an illustrative example in the use of water power in manufacturing applications which later came to use steam**….The new power source could be used where and when it was cheaper or more valuable, as steam could be when the water was not flowing (reliably). **More generally, if the complementary innovations used with an earlier technology are not (prohibitively) specific to it, they can also become complements of the new GPT**….

“This dynamic complementarity should not come as a surprise. **Much of technical progress is recombinant. Recombination of existing complementarity innovations with a new GPT is just one version of that**.” (Bresnehan, pp, 771-2)

(See: Brian Arthur, *The Nature of Technology: What It Is and How It Evolves* (Free Press, New York: 2009)

Electricity in Manufacturing

"The electrification of manufacturing plants and processes had invention divided between applications sectors and GPT inventors….

"**To be sure, at the beginning electric motors replaced steam engines in many manufacturing plants without much new co-invention**. The complex system of belts and drives used to move hard-to-divide steam power could also transmit the power of a large electric motor….

"…**Electric motors could be made much smaller than steam engines. This enabled the distribution of the power source to specific locations within the manufacturing plant**. This distribution came to be called 'unit drive'….The advantages of unit drive were that it permitted industrial engineers to redesign plants to follow the logic of the manufacturing process….

"….**If small plants were to be electrified, they could share generating equipment…only with an electrical distribution system in place**…." (Bresnehan, pp. 775-6)

(See A. J. Field, *A Great Leap Forward: 1930s Depression and U.S. Economic Growth* (Tale University Press, New Haven CT, 2012)

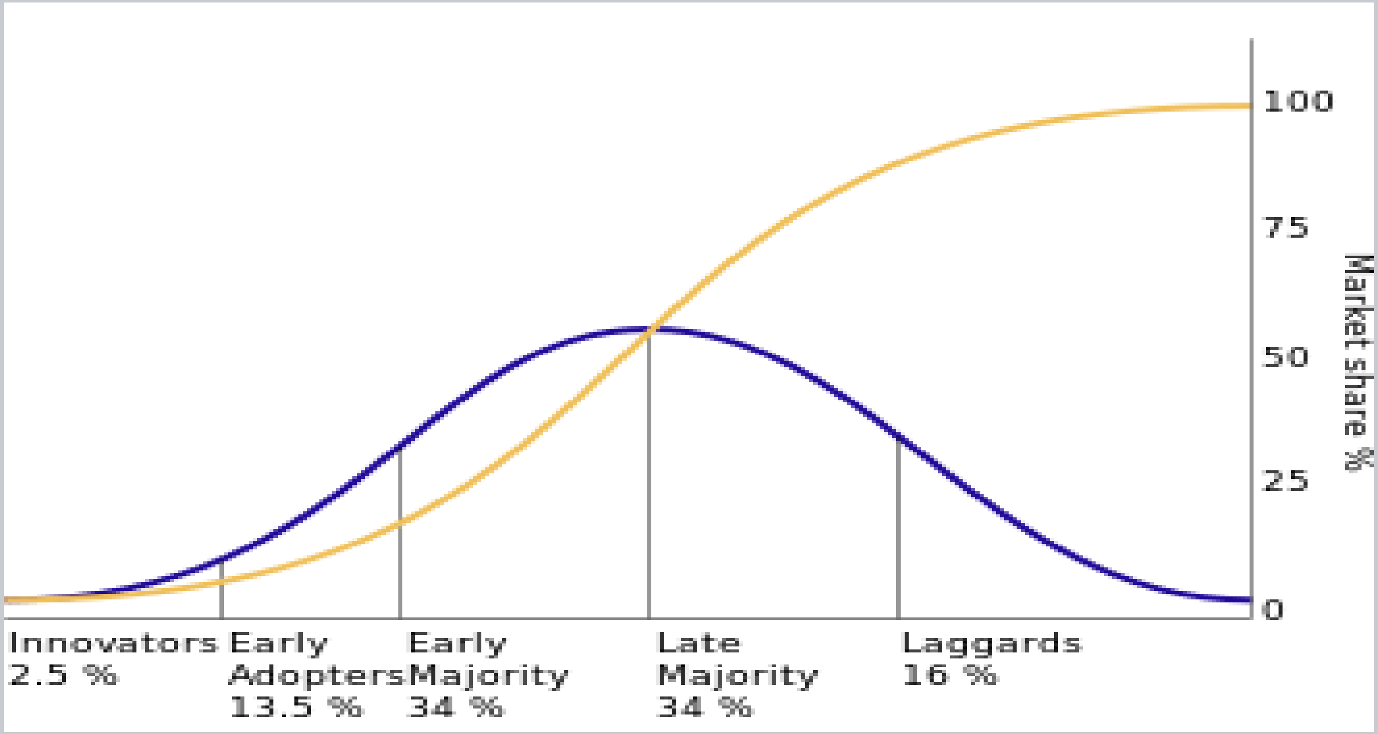
Electricity: Deployment as Systems

"**Some important applications of electricity were, in contrast to steam, organized and distributed as a supply network with coordinated invention of a number of different technologies**. The telegraph, drawing on earlier inventions, was itself invented as a communications system. So too was the telephone later on. The city electric light company, with generation system, distribution system, lights at end of wires, was supplied as a system. The city public transportation system built around the electric rail/trolley was another system….

"At a minimum **these historical examples illustrate the varied industry structures and information structures which can accompany the founding of a GPT.** Some electrical applications…were invented in coordinated ways as a system. This stands in contrast to steam power, where different technologies were invented far apart…."

(Bresnehan, p. 775)

Technological Diffusion



The diffusion of innovations according to Rogers. With successive groups of consumers adopting the new technology (shown in blue), its market share (yellow) will eventually reach the saturation level. The blue curve is broken into sections of adopters.

(E. Rogers, *Diffusion of Inventions*, 1962)

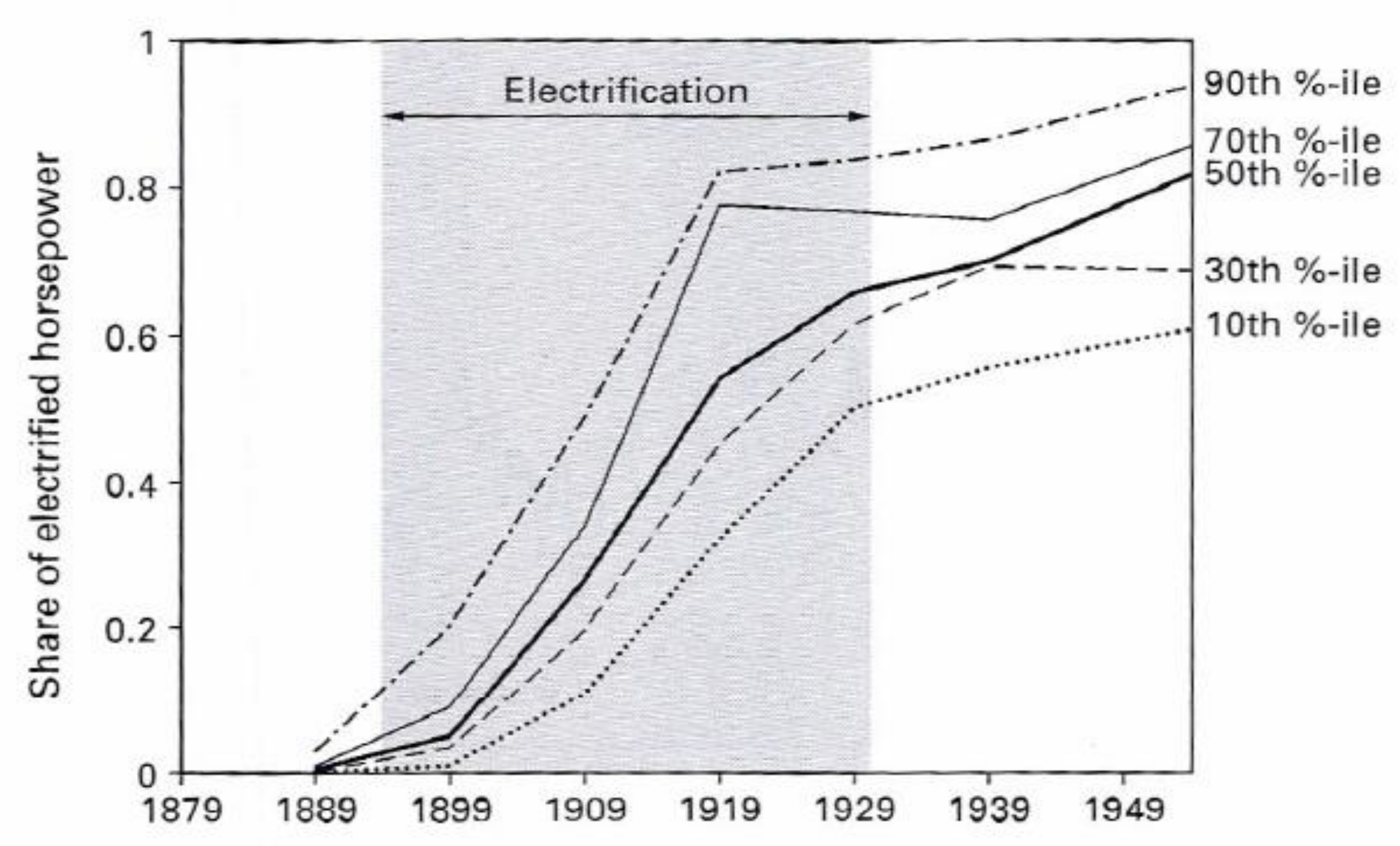
The Diffusion of Electrification

"**Certainly, the transformation of industrial processes by the new electric power technology was a long-delayed and far from automatic business**. It did not acquire real momentum in the United States until after 1914-17, when regional utility rates for electricity were lowered substantially…and central station generating capacity came to predominate over generating capacity in isolated industrial plants.

"In 1900 contemporary observers well might have remarked that the electric dynamos were to be seen "everywhere but in the productivity statistics."

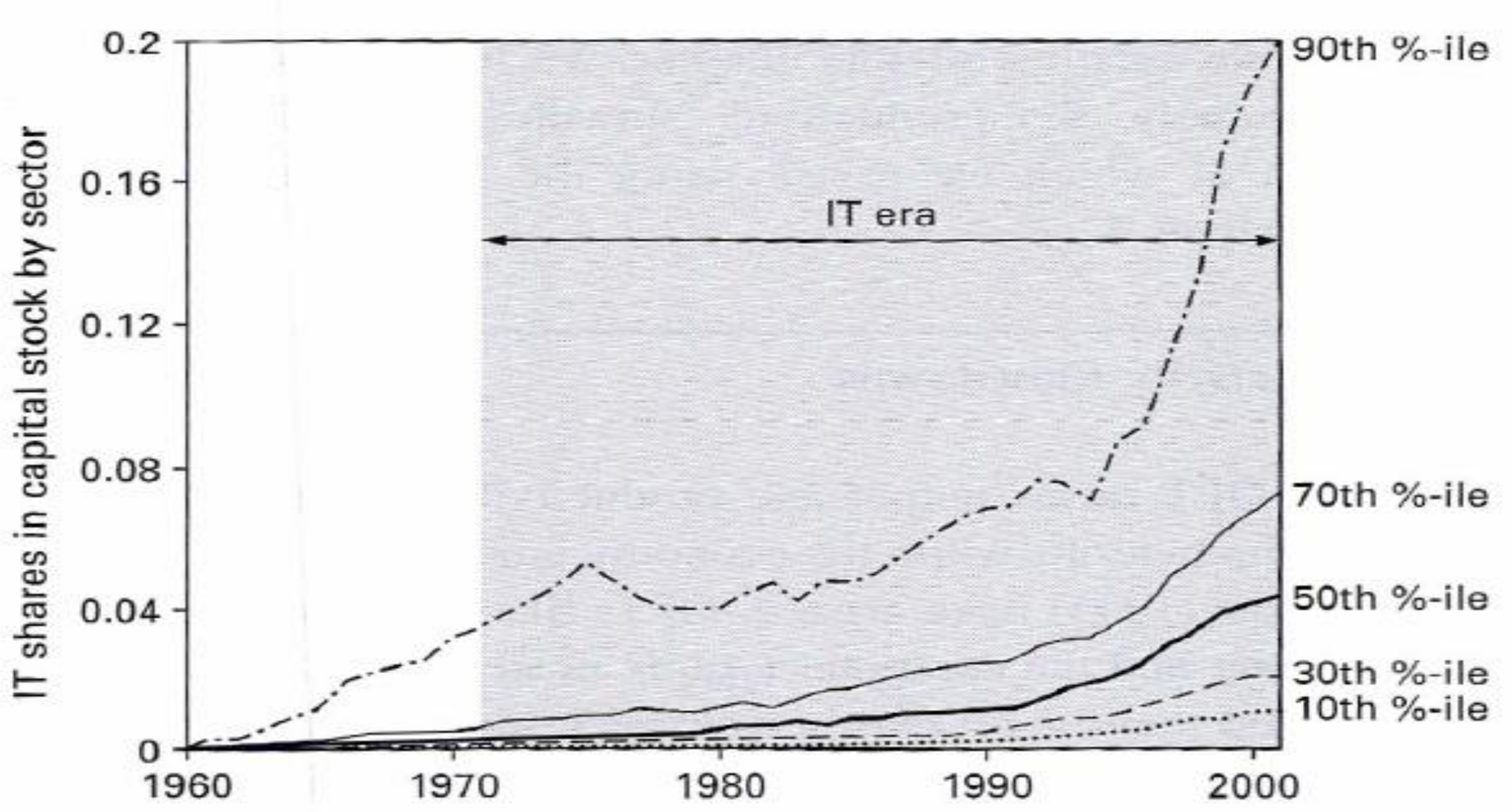
(P. A. David, "The Dynamo and the Computer: An Historical Perspective on the Modern Productivity Paradox," *American Economic Review*, May 1990, p. 355)

Shares of Electrified Horsepower by Manufacturing Sectors in percentiles: 1890-1954



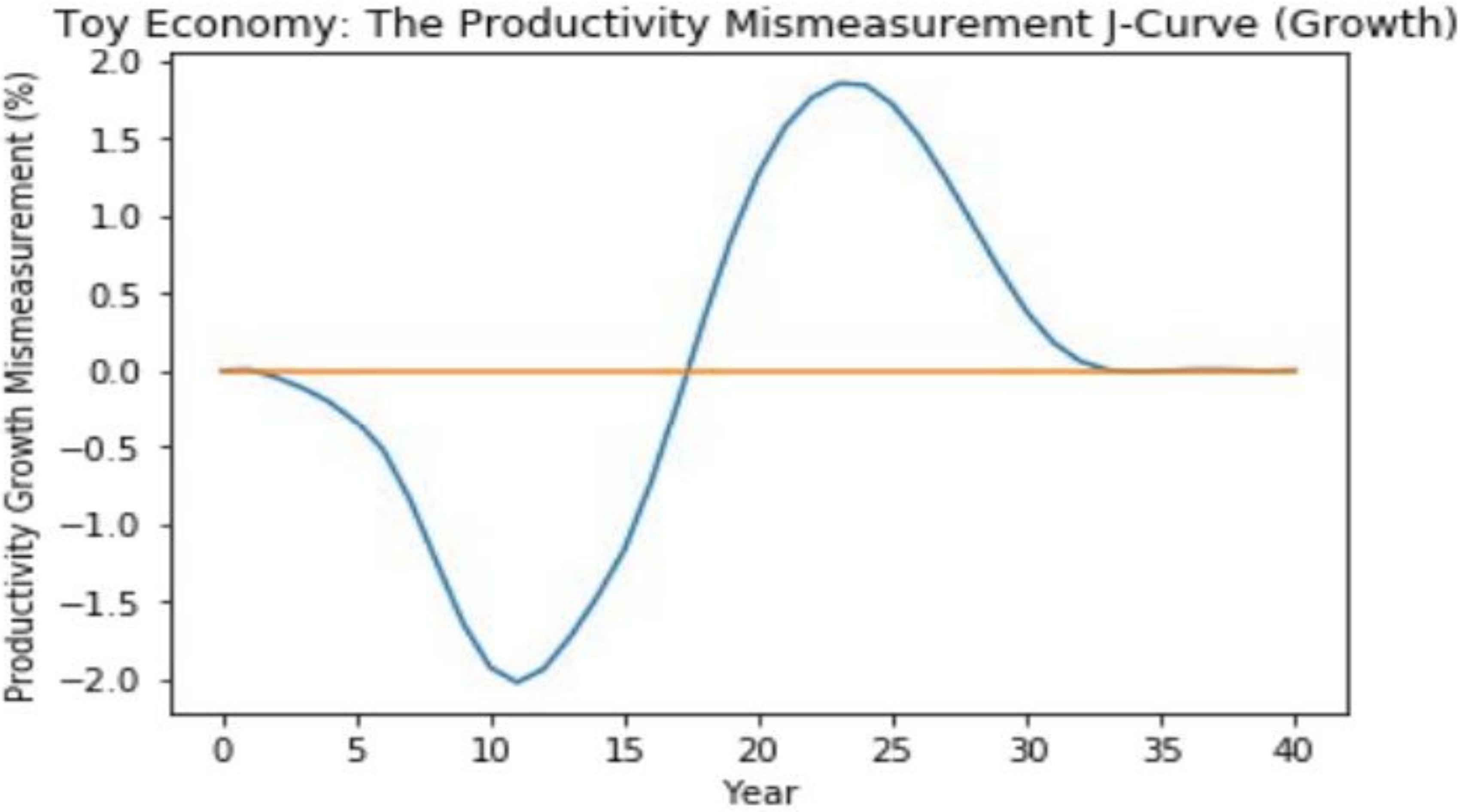
(B. Jovanovic and Rousseau, P. L., “General Purpose Technologies” (2005) in P. Aghion and Durlauf, S. (eds.) *Handbook of Economic Growth*, Amsterdam: Elsevier)

Shares of IT Equipment and Software in the Capital Stock by Sector in percentiles, 1960-2001



(Jovanovic and Rousseau, “General Purpose Technologies”)

The Productivity J-Curve



(E. Brynjolfsson, Rock, D., and Syverson, C., “The Poductivity J-Curve: How Intangibles Complement General Purpose Technologies,” NBER working paper 25148, October 2018)

Macro-Consequences of New GPT

“**Although each GPT raises output and productivity in the long run, it can also cause cyclical fluctuations while the economy adjusts to it**…. GPTs like the steam engine, the electric dynamo, the laser, and the computer require costly restructuring and adjustment to take place, and there is no reason to expect this process to proceed smoothly over time. Thus, contrary to the predictions of real-business-cycle theory, the initial effect of a ‘positive technology shock’ may not be to raise output, productivity, and employment but to reduce them.

“…[E]ach GPT requires an entirely new set of intermediate goods before it can be implemented. The discovery and development of these intermediate goods is a costly activity, and the economy must wait until some critical mass of intermediate components has been accumulated before it is profitable for firms to switch from the previous GPT. **During the period between the discovery of a new GPT and its ultimate implementation, national income will fall** as resources are taken out of production and put into R&D activities aimed at the discovery of new intermediate input components.”

(Aghion et. al., “What Do We Learn from Schumpeterian Growth Theory?” NBER Working Paper 18824, February 2013, p. 29)

Macro Consequences of New AS:
The Contested Case of the US Railroads

“We examine how the expansion of the railroad network impacted manufacturing productivity, along with other measures of manufacturing activity….

“…[W]n reduced-form regressions, we find that county manufacturing productivity increases substantially with relative increases in county market access. **A one standard deviation greater increase in county market access increased county manufacturing productivity by 12.9% from 1860 to 1880**….

“We estimate that **US aggregate productivity would have been 25% lower in 1890, in the absence of the railroads, with an associated annual loss of $3 billion or 25% of GDP. This annual economic loss, as a share of GDP, is much larger than previous estimates** of 3.2% (Donaldson and Hornbeck, 2016) or 2.7% (Fogel, 1964). When including our estimated impacts on annual productivity, **we estimate a 43% annual social rate of return on the $8 billion of capital invested in the railroads in 1890 (in 1890 dollars), and estimate that the railroads in 1890 privately captured 8% of this social return**.”

(R. Hornbeck and Rotemberg, A, “Railroads, Reallocation, and the Rise of American Manufacturing,” NBER Working Paper 26594, December 2019). Pp. 1-2.)

The Role of the State in Accelerating GPT: Carrots

"One mechanism through which defense-related R&D investments can aid innovation is **military funding for new bodies of scientific or engineering knowledge that supports innovation in both defense-related and civilian applications**….This channel…is likely to produce the greatest benefits…in basic and applied research, rather than development.

"A second important channel through which defense-related R&D affects civilian innovative performance are **the classic 'spin-offs**,'…[C]ivilian spin-offs…appear to be most significant in the early stages of development of new technologies…[before] civilian and military requirements…diverge….

"A third important channel…is **procurement**….The US military services…have played a particularly important during the post-1945 period as 'lead purchaser'….

"Defense-related research spending contributed to **the creation of a university-based US 'research infrastructure'** during the postwar period that has been an important source of civilian innovations, new firms, and trained scientists and engineers…."

(D. C. Mowery, "Military R&D and Innovation," in B. W. Hall and Rosenberg, N., *Handbook of the Economics of Innovation* (Amsterdam: Elsevier, (2010), pp. 1236-7)

The Role of the State in Accelerating GPT: Sticks

“**The procurement reforms and financial cutbacks of the Department of Defense were initiated by the Eisenhower Administration and greatly accelerated by Robert McNamara**…In the first half of the 1960s, the Department…canceled weapon systems already under development and halted the deployment of others….McNamara reinforced this policy by introducing improved inventory control….

“…[T]he Department…reformed the production process to effect price reductions…[and]…also pressed more forcefully for second sourcing…and…increasingly fixed-price contracts….(p. 171)

“**The ‘McNamara Depression’** led to the consolidation of the microwave tube industry on the Peninsula; it also **re-oriented the area’s electronic component firms toward the civilian markets….They learned how to create markets for their products in the commercial sector**, notably by giving technical support to the users….(pp. 180, 208)

(C. Lécuyer, *Making Silicon Valley, Innovation and the Growth of High Tech, 1930-1970 (Mit Press, Cambridge MA, 2007)*

Schumpeter Mark III?
"Division of Innovative Labor"

"**If innovating firms indeed commonly rely upon extramural sources for inventions, then economists' understanding of the fundamental drivers of innovation requires amendment and the adoption of a more system-wide perspective**. The overall rate and quality of innovation would then depend not only upon industry-level factors (e.g., demand, technological opportunity and appropriability) and firm characteristics (e.g. firms' R&D capabilities, firm size), but also upon the extramural supply of inventions.

"**The availability of external sources of invention also offers social welfare benefits**. **First there are gains from trade**. When the firms best equipped to invent are not necessarily the firms most capable of commercializing invention, society benefits when rights over an invention can transfer between in**…[a] 'division of innovative labor.'** Economic theory, starting with Adam Smith, further suggests that such a division of innovative labor should also confer system-wide efficiencies through increases in specialization."

(A. Arora, Cohen, W., M. and Walsh, J. P., 2016. "The acquisition and commercialization of invention in American manufacturing: Incidence and impact," *Research Policy*, Elsevier, vol. 45(6), pp., 2-3.)

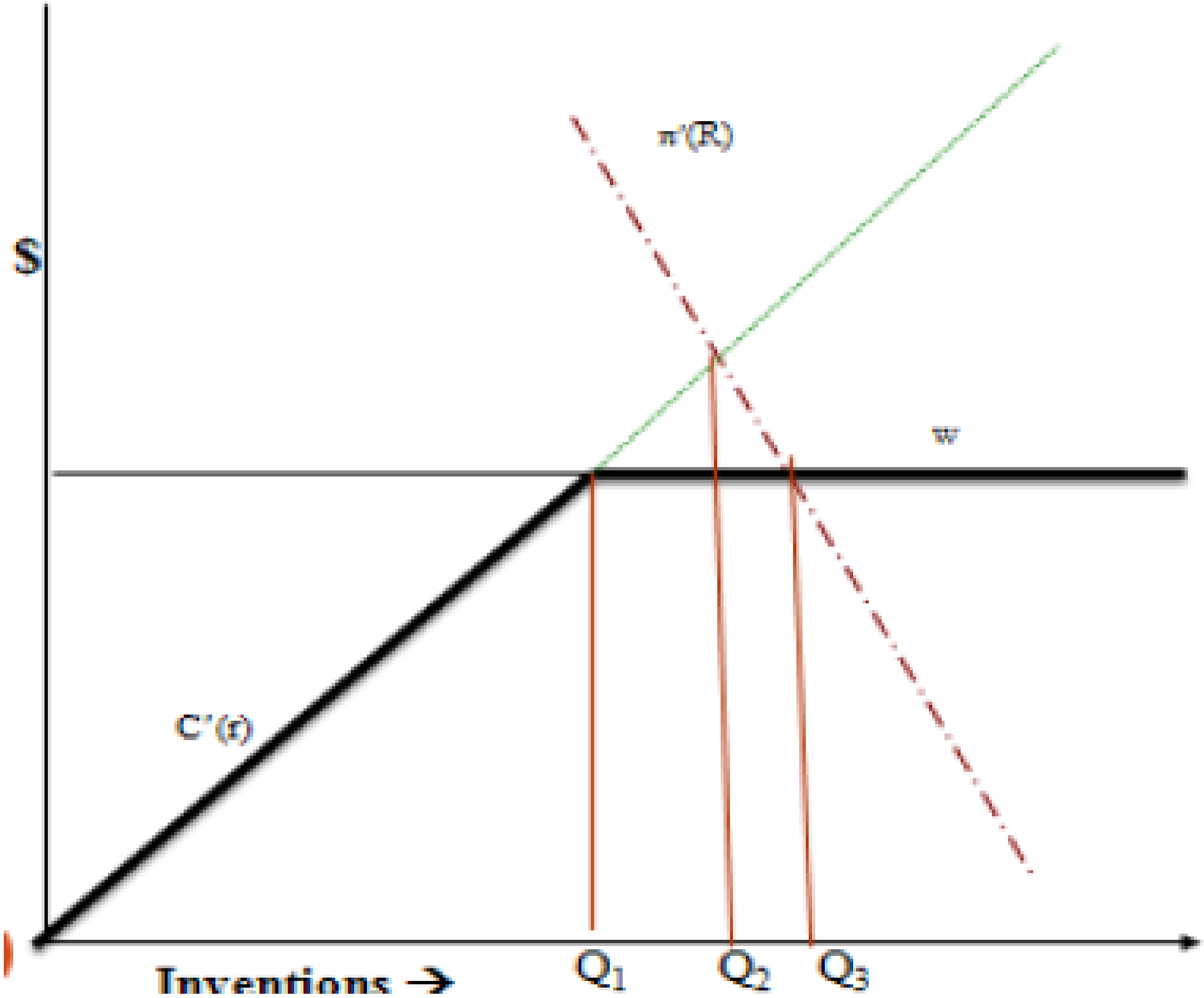
Schumpeter "Mark III"? A Simple Model

"…**External sources of invention do not, however, simply provide a choice between internal R&D and the purchase of an invention from an outside source. The availability of external invention may also affect whether a firm decides to innovate. Thus, external availability of inventions may affect not only the efficiency of innovation, but also the overall rate of innovation.**

"A simple model illustrates these two effects of external supply of invention on firm innovation. In Figure 1, we assume that the firm has **a demand schedule for invention derived from product market demand**. We also assume it faces an **upward marginal cost schedule for invention, which represents the cost of generating innovation internally**. Without external supply, **the equilibrium quantity of inventions is Q2**. We further assume, however, that **the firm can access external inventions at a constant cost, w**. Transaction costs, defined broadly to include contracting and search costs as well as the costs of transferring knowledge across contexts and firm boundaries, are a component of w. Figure 1 allows us to make two points. First, it shows that **the availability of externally sourced invention can increase the overall rate of innovation from what it would be in the absence of external supply, in this case from Q2 to Q3**. Second, the presence of external sources of invention also yields **some substitution of external inventions for internal inventions, represented by Q2 - Q1**. Thus, we expect the supply of external technology to affect both the overall rate of innovation and the share of internally generated innovations."

(Arora et. al., pp. 5-6

Figure 1: Supply and Demand for Innovation



Schumpeter "Mark III"? Summary Results of Survey

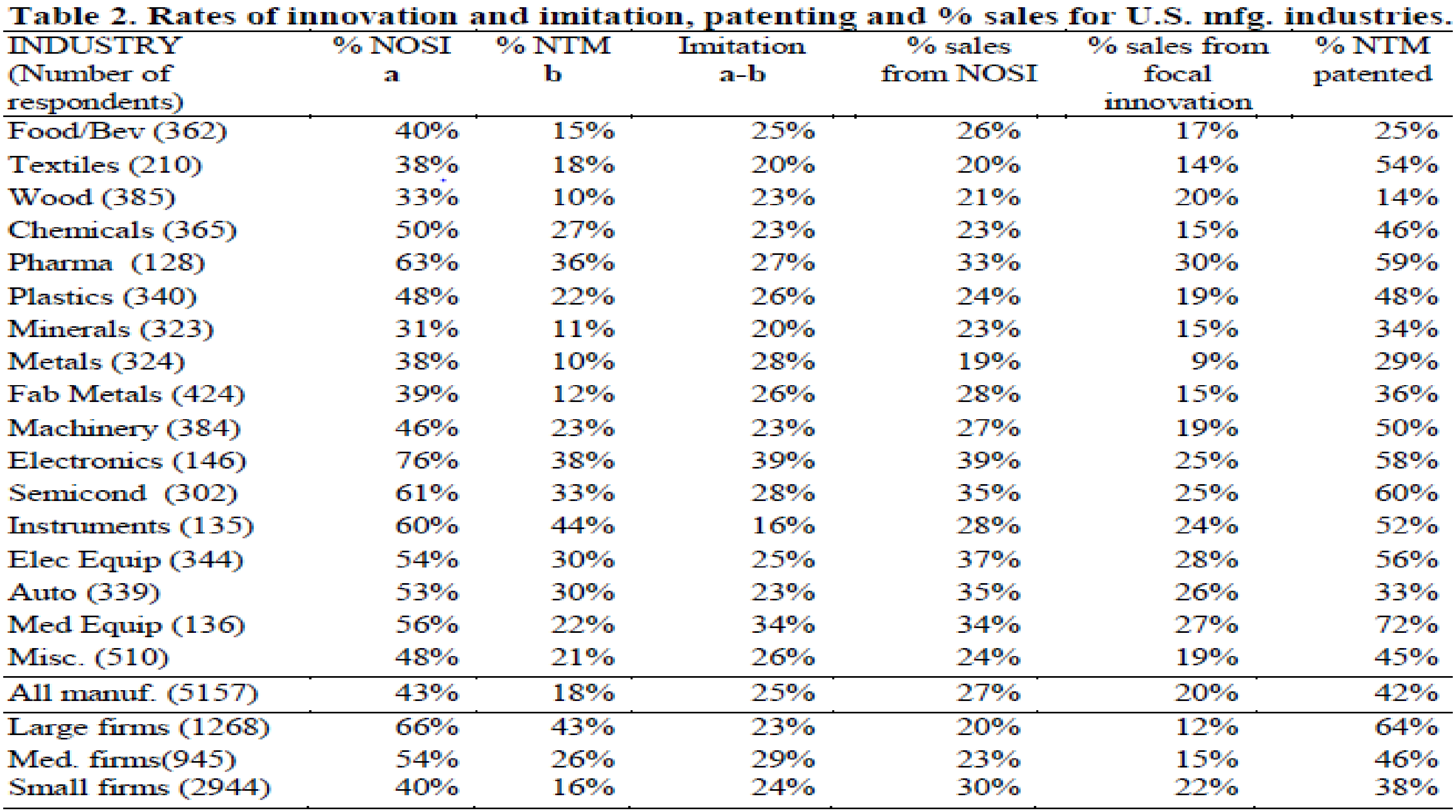


Table 2. Rates of innovation and imitation, patenting and % sales for U.S. mfg. industries.

INDUSTRY (Number of respondents)	% NOSI a	% NTM b	Imitation a-b	% sales from NOSI	% sales from focal innovation	% NTM patented
Food/Bev (362)	40%	15%	25%	26%	17%	25%
Textiles (210)	38%	18%	20%	20%	14%	54%
Wood (385)	33%	10%	23%	21%	20%	14%
Chemicals (365)	50%	27%	23%	23%	15%	46%
Pharma (128)	63%	36%	27%	33%	30%	59%
Plastics (340)	48%	22%	26%	24%	19%	48%
Minerals (323)	31%	11%	20%	23%	15%	34%
Metals (324)	38%	10%	28%	19%	9%	29%
Fab Metals (424)	39%	12%	26%	28%	15%	36%
Machinery (384)	46%	23%	23%	27%	19%	50%
Electronics (146)	76%	38%	39%	39%	25%	58%
Semicond (302)	61%	33%	28%	35%	25%	60%
Instruments (135)	60%	44%	16%	28%	24%	52%
Elec Equip (344)	54%	30%	25%	37%	28%	56%
Auto (339)	53%	30%	23%	35%	26%	33%
Med Equip (136)	56%	22%	34%	34%	27%	72%
Misc. (510)	48%	21%	26%	24%	19%	45%
All manuf. (5157)	43%	18%	25%	27%	20%	42%
Large firms (1268)	66%	43%	23%	20%	12%	64%
Med. firms(945)	54%	26%	29%	23%	15%	46%
Small firms (2944)	40%	16%	24%	30%	22%	38%

(Arora et. al., Table 2, p. 11)

Schumpeter “Mark III”?
Sources of Inventions

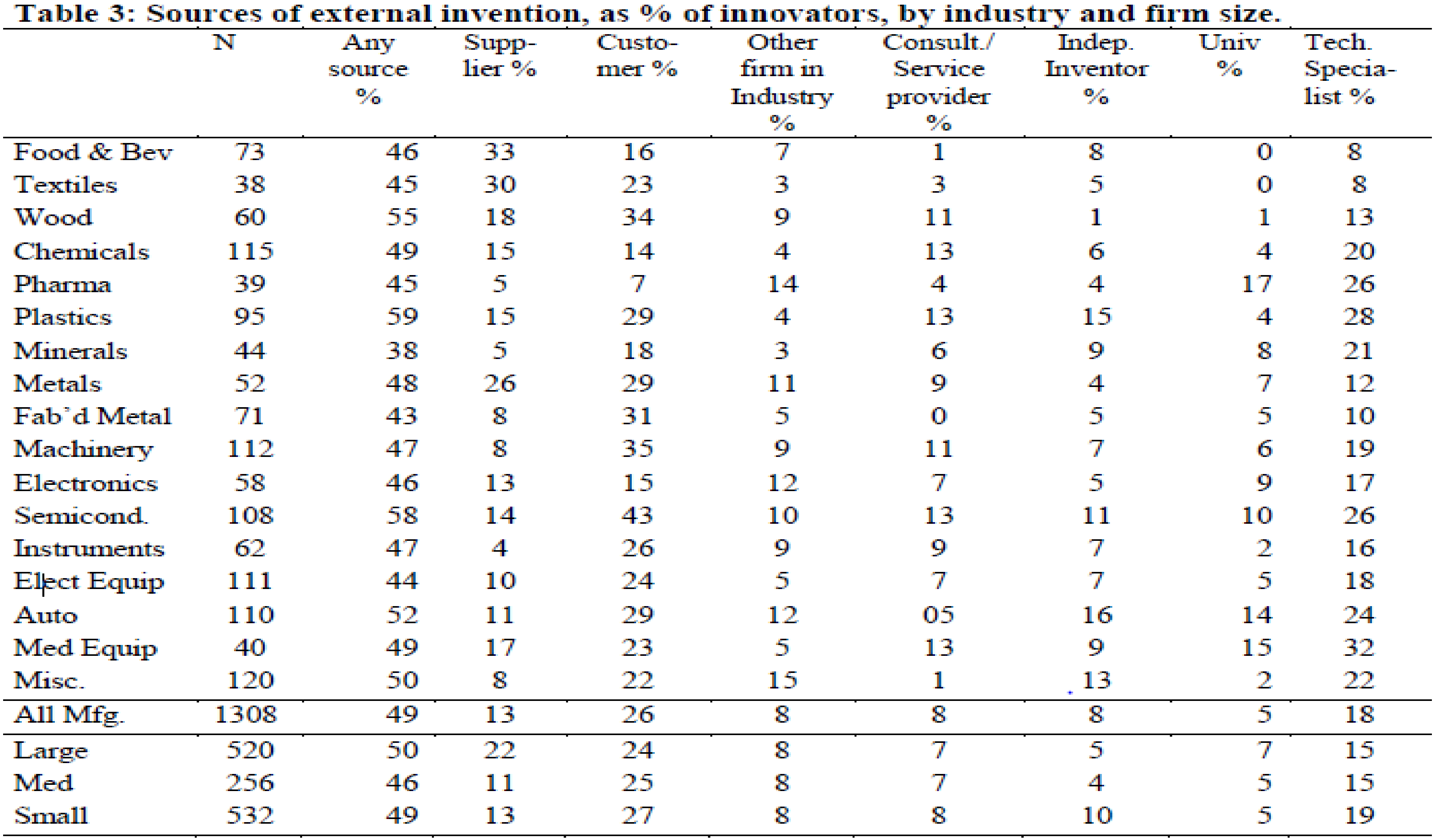


Table 3: Sources of external invention, as % of innovators, by industry and firm size.

	N	Any source %	Supp-lier %	Custo-mer %	Other firm in Industry %	Consult./ Service provider %	Indep. Inventor %	Univ %	Tech. Specia-list %
Food & Bev	73	46	33	16	7	1	8	0	8
Textiles	38	45	30	23	3	3	5	0	8
Wood	60	55	18	34	9	11	1	1	13
Chemicals	115	49	15	14	4	13	6	4	20
Pharma	39	45	5	7	14	4	4	17	26
Plastics	95	59	15	29	4	13	15	4	28
Minerals	44	38	5	18	3	6	9	8	21
Metals	52	48	26	29	11	9	4	7	12
Fab'd Metal	71	43	8	31	5	0	5	5	10
Machinery	112	47	8	35	9	11	7	6	19
Electronics	58	46	13	15	12	7	5	9	17
Semicond.	108	58	14	43	10	13	11	10	26
Instruments	62	47	4	26	9	9	7	2	16
Elect Equip	111	44	10	24	5	7	7	5	18
Auto	110	52	11	29	12	05	16	14	24
Med Equip	40	49	17	23	5	13	9	15	32
Misc.	120	50	8	22	15	1	13	2	22
All Mfg.	1308	49	13	26	8	8	8	5	18
Large	520	50	22	24	8	7	5	7	15
Med	256	46	11	25	8	7	4	5	15
Small	532	49	13	27	8	8	10	5	19

(Arora et. al., Table 3, p. 15)

Schumpeter "Mark III"?
Value of External Inventions by Source

"…Going beyond estimating the effect of external supply on the innovation rate overall, we can also distinguish the impacts by source, distinguishing particularly between customers and technology specialists. An important implication of our analysis is that the relative incidence of reliance on a given source reflects both the value of inventions offered by the source as well as the cost of acquiring and commercializing the invention from the source. By exploiting data on the share of sales accounted for by our respondents' most significant product innovations, we are able to show that, **although customers are a pervasive external source for innovation, the value of the innovations originating from customers tends to be relatively low, and the highest value externally acquired innovations originate from technology specialists**."

(Arora et. al., p. 28)

Schumpeter "Mark III"? Channels for Acquisition of Invention

"…**It appears that the more technology intensive sectors favor market channels**. Indeed, one of the most R&D intensive industries in manufacturing, **pharmaceuticals, stands quite apart from almost all other industries in its high reliance upon market channels**, with 47% of the respondents reporting use of market channels alone, particularly acquisitions and licensing. More generally, **if we use the fraction of firms in an industry that perform R&D as a measure of an industry's technological intensity, we find that technology intensity is positively related to the use of market channels, with a correlation coefficient of 0.57.** This suggests that the type of channels used may be related to the nature of innovation, such as the extent to which it is science based, and therefore easier to codify, or protect through patents, and, in turn, transfer across firm boundaries.

"Among respondents that reported a channel, 27.7% of the inventions sourced externally were patented by the source. **Unsurprisingly, inventions sourced via licensing, or a merger and acquisition, are most frequently reported to be patented—58% for inventions sourced via a merger or acquisition, and 69% via licensing**…." (Arora, et. al., p. 18)

Schumpeter "Mark III"? Importance of Start-ups

"Our data also indicate the extent to which startups may be a source of inventions for firms that rely on external sources. On average, across all sources, **14% of those firms relying upon an outside source for their invention report that the source is a startup (defined as a "new, small company").** Unsurprisingly, the source most often characterized as a startup—by 37% of the respondents—is independent inventors. **Our aggregate figure of 14% for the contribution of startups to other firms' innovative activities is striking when compared to the incidence of startups in our manufacturing sample more generally, which is 2.5%,** suggesting that startups play a disproportionately important role in the division of innovative labor."

(Arora et. al., p. 16)