THE MEASUREMENT OF INNOVATION

AND ITS CONSEQUENCES

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TechMatt™
BUSINESS INNOVATION ANALYSIS

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Introduction

TechMatt™ Business Innovation Analysis delivers new metrics that are useful for understanding the effects of innovation in our economy, and on our quality of life.

What is innovation?

Innovation is the (commercial) realization of invention[1].

How were the metrics derived?

The metrics were derived commercially using unique access to tacit knowledge and data that is not readily available elsewhere. TechMatt™ Business Innovation Analysis relies heavily on this insider knowledge to

1. Assemble a five-decade multiple-product database, vastly more comprehensive than ever assembled before, from which the effect of innovation in the economy could be made to emerge.

2. Use new tools to tweeze it out – these tools being derived from actual innovation observed happening from factory floor, technical center and corporate office.

I was guided by academic knowledge where it existed and where it fitted[2], but where it didn't I relied on the tacit knowledge that surrounded me daily. I applied lateral thinking to this highly interdisciplinary source and to observations of the following actual economic workings of industry to make TechMatt™ Business Innovation Analysis deliver many otherwise unachievable results.

Industrial Observation 1.

The price of an innovative product is dominated by two considerations (a) the advantage of the new product in the eyes of the purchaser and (b) the current price of similar competitive ones.

This can be expressed by the simple equation

$$P = F(p, C, I) \qquad \text{MELF}$$

Where P is price of the innovative product, and p is its performance perceived by the purchaser[3] and C measures competition[4].

[1] The bracketing of (commercial) recognizes that some innovations do not arise within commerce itself, although they invariably depend on intermediates that did; or do.

[2] For example, tacit knowledge does not fit in with any kind of indifference.

[3] Where performance, p, corresponds to what is called 'quality' in Economics (quality having an entirely different meaning in manufacturing since the seminal work of Edwards Deming and Crosby).

[4] By introducing the term '*quality competition'* Joseph Schumpeter partially anticipated this in *The Process of Creative Destruction, Chapter VII*, Capitalism, Socialism and Democracy, Harper (1975).

The function F connects P with p, C and I – where I is an inflation index, accounting for changes in the value of money over time.

Discovering the form of F, C and I became the principal aims of this research, where the function F is universal[5] and applies to both good and services, including public services.

Such an equation would also provide the lens of the 'macroscope' sought by the Industry Studies initiative at the Sloan Foundation[6] when re-focused to

$$p = G(P, C, I) \qquad \text{MELF}^{7}$$

Where the fundamental metric, p, can now be calculated from P, C and I [8].

If p were expressed in engineering units it would correspond to the original measurement of innovation used by Richard Foster in his pioneering work in the 1980s[9]. In contrast, the market evaluation achieved by the MELF recognizes engineering merit only to the extent that the end - user perceives value in it. Thus it transcends engineering and neatly integrates all factors that enter a purchasing decision into p, overcoming the weakness of relating the innovative performance of products or services to attributes, such as is done in hedonic[10] and most factor, and indicator analyses[11]. All attributes – intangibles and behaviorals – are included without tying them to individual choice or identifying factors individually.

And because every buyer makes an implicit benefit assessment of well – being for themselves or for their loved ones or for their communities at point of purchase, the aggregate of their perceptions is a measure of well – being; very simply captured by $\sum p$, providing the perception surrounding the continued use of older durable goods and equipment within their service lives is also included. This allows quality-of-life or social well - being to be enumerated[12]

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5 Following the example of Robert Hooke F.R.S., and for similar reasons, the universality of F is encapsulated by an anagram *bceeeeffiiiimoprrssstttuuv*

6 www.techmatt.com/techmatt/Industry_Studies_Gomory.pdf

7 MELF = **M**acroscopic **E**conomic **L**ens **F**ormula.

8 Thus overcoming the longstanding impediment to Economics - no methods for calculating the goodness of a good or service – its so-called 'quality change problem'.

9 My Department of Commerce paper reviews his work www.techmatt.com/techmatt/Farrell0308.pdf

10 Hedonic methods survey product prices, P_i, in conjunction with attributes a_{ij}. An equation $\log_e P_i = \alpha a_{i1} + \beta a_{i2} + \ldots$ is derived by regression of prices against attributes. Subsequent innovation will have produced new values of the attributes $a_{i1}, a_{i2} \ldots$ and by substituting these back into the equation the probable effect on P_i can be estimated. When subtracted from the P_i 's actually observed the effect of 'quality improvement' on price can be adjusted out for calculating price indices, such as the consumer price index. Although the hedonic equation $\log_e P_i = \alpha a_{i1} + \beta a_{i2} + \ldots$ appears to be similar to $P = F(p, C, I)$ it completely misses the effect of competition on price. This, and the inherent limitations of attributes for capturing innovation, is exactly what the complementary equation $P = F(p, C, I)$ so elegantly overcomes.

11 Any indicator that relies on surveys falls into this category, with attributes implicit in the questions.

12 Applications to Quality of Life and Well-being are explored in a separate document www.techmatt.com/techmatt/Quality_Of_Life_Measurement.pdf

Our[13] analysis hinges - not a theory of price, as is found in Economics, but on an explanation of price. The distinction between these two is essential and is perhaps best understood by looking at an economic text on the theory of price. George Stigler's 'Theory of Price' reached its fourth edition in 1987, five years after he won the Nobel Prize in Economics[14]. The book contains 79 graphs that have imaginary lines because there are no data points for them to connect. It has 24 tables of numbers, but only one contains actual data. The other numbers are made up. This lack of commercial data input is very limiting[15].

Explanation must be dominated by data that simple equations must fit. And when you can explain you can predict. Confirmation includes making a prediction and verifying it. Unlike the Stigler approach, the forms of F, G, C and I within TechMatt™ Business Innovation Analysis meet these explanation objectives.

Industrial Observation 2.

Competition requires two adjectives to describe it. These are (a) ruthless and (b) relentless.

If you have ever shared the duty of protecting your company from the effects of competition, these terms will resonate with you[16]. But if you were taught to think of competition as 'perfect' (or imperfect) abstractly in an Economics class, then put ruthless and relentless into a new sub-category 'extremely imperfect'.

At first it may seem impossible to quantify competition using these two new adjectives.

However, ruthless is a characteristic of a single organization whereas relentless is dependent on many. Therefore C must contain both one and many, an important clue to how it may be mathematically represented.

TechMatt™ Business Innovation Analysis provides a way to express C that has been verified and validated against actual data. The resulting equation contains parameters that, in the limit of a monopoly, still give competition C a positive value[17]. This may surprise because competition is supposed to be absent from a monopoly. In fact it is truer to say that monopolists choose not to compete with themselves. Competition is not so

[13] 'Our' refers to the tacit knowledge that permeates commerce, from which Business Innovation Analysis was synthesized.
[14] Stigler G.J., *The Theory of Price*, The Macmillan Company.
[15] The Sloan Foundation has recognized this and has tried to overcome it in University settings. But industry insiders – innovation professionals – are far better positioned to understand innovation. Anyone not actually participating in the literature of commerce (its patents) and in its institutions (factories, corporate offices and technical centers) is at a strong disadvantage by comparison with those who inhabit these domains.
[16] Joseph Schumpeter's *'ever present threat'* is a symptom of this. *The Process of Creative Destruction, Chapter VII*, Capitalism, Socialism and Democracy, Harper (1975).
[17] In this limit relentlessness will relent and ruthlessness will become benign, but C still contributes to p.

much absent as virtual, and thereby dormant. This paves the way to measuring innovation in public services. Public Services are essentially monopolistic and being able to determine their virtual C allows p, their innovation metric, to be enumerated also.

Industrial Observation 3.

The products of an industry are determined by the very long run happening in a very short time.

This is an essential characteristic in an era of rapid technological change.

In the automobile industry 224 innovations were introduced between 1954 and 1974[18], close to one a month. For a single company and for a single car, the Volkswagen Beetle, there were at least 151 lesser improvements between 1954 and 1974[19], one every six weeks.

Because development anticipates the market what may seem to be 'very long run' can and does actually occur in 'a very short time'.

This inherent condition is an essential pre-cursor to the following corollary.

Inflation without bias is found from the change in general price, not from the general change in prices.

A market basket is currently used to determine a general change in prices, such as the consumer price index (CPI). Market baskets originated in the 18th century when innovative change was miniscule over long periods of time[20]. Today, because the very long run occurs in a very short time, goods in such a basket change from month to month. Comparing like with like is an almost impossible task – and that introduces bias.

The Boskin Commission estimated total bias for 1995-6 to be about 1.1%, of which 0.6% was attributed to innovation[21]. Although small in absolute terms, when compared to the CPI rise of 3% the relative error is much larger ~ 20%, enough for existing price indexes to interfere in the proper measurement of innovation.

For measuring innovation without introducing significant error, TechMatt™ Business Innovation Analysis provides an inflation index free of innovation bias. This was achieved by switching from 'general change in prices' to 'change in general price', which

[18] Abernathy W.J., Clark K.B., & Kantrow A.M., *Industrial Renaissance*, Basic Books Inc., (1983), Table D.1 lists 631 automobile innovations 1893-1981.
[19] Meredith, L., *Original V.W. Beetle*, Bay View Books, (1994). Lists of model changes for enthusiasts.
[20] Diewert W.E. *The Early History Of Price Index Research*, Essays in Index Number Theory, Volume I, Chapter 2, Elsevier (1993).
[21] Gordon R.J., *The Boskin Commission Report and its Aftermath*, Working paper 7759, National Bureau of Economic Research (2000).

is the total value in a basket divided by total quantity[22]. This eliminates bias. It also eliminates the need to compare like to like and is therefore more suited to eras of rapid technological change.

General price has a numerator in quantity of money and a denominator in quantity of goods. This not only corresponds to Milton Friedman's assertion that 'inflation is always and everywhere a monetary phenomenon' but also quantifies the Economist definition that 'inflation is too much money chasing too few goods'.

The problem is that there is no current means for measuring the denominator, total quantity. Unfortunately in the 1920's Irving Fisher could not find a way to add bushels of grain to tons of metal to heads of cattle[23] and this left its mark on Economics. Since then macro-quantity has always been calculated by dividing actual value by a price index, producing an awkward derivative with no unit behind it.

By adapting concepts from Industrial Design and bringing them to bear on this problem a new universal unit of quantity, the quantil, is created.

The general price can then be determined from a market basket by dividing its total value by its total quantity. The litmus test is that the bias must lie within the plausible Boskin Commission range of 0.8 – 1.6%, compared to the CPI for 1995-96, and it does[24].

And the function G becomes simpler when I is substituted for the CPI in the equation p = G (P, C, I), strongly indicating a movement towards the way things really are[25].

These three new observational tools were brought to bear on the problem of explaining economic growth in the following four research phases.

I. Data Collection & Collation

II. Validating the Metric Equations

III. Aggregating the Metric; Explaining GDP

IV. Disaggregating the Metric; Innovation in Firms

[22] 'general change in prices' is taken from James Tobin's '*Inflation*' entry in the McGraw-Hill Encyclopedia of Economics, Second Edition p 530-542. The rearrangement to 'change in general price' better suits eras of rapid technology change.
[23] Fisher I., *The Purchasing Power of Money* (1922). Reprinted by Augustus M. Kelley (1971), especially Chapter IX, Sec. 3, page 196.
[24] Document www.techmatt.com/techmatt/InflationIndex_2.pdf shows biased and unbiased indices graphed together.
[25] *'you know you are getting somewhere when the equations start looking beautiful and you know numbers are taking you closer to the secret of how things are'* words of Tom Jericho, a fictional Alan Turing, written by Tom Stoppard for the movie Enigma (2001).

I. Data Collection & Collation

DINTEC™ (Data on INnovation, TEchnology & EConomics) covers the period 1951-2001[26].

Five decades of annual data were needed because (a) stochastic fluctuations confuse interpretation of short period data and (b) foreign trade in manufactured goods becomes significant only after the mid – 1970's – so a database with this midpoint allows the effects of foreign trade on innovation to be deciphered.

The primary source was the Census of Manufactures published every five years. Data for intervening years was taken from the Annual Survey of Manufactures and Current Industrial Reports. These were supplemented by data from industry sources and associations such as The Almanac of the Canning, Freezing, Preserving Industries, Can Manufacturer's Institute, Frozen Food Institute, Carpet & Rug Institute, Association of Home Appliance Manufacturers, Motor Vehicle Manufacturers Association, Ward's Automotive, Consumer Electronics Association, Dealerscope Merchandizing, Business Technology Association and the Writing Instrument Manufacturers Association. Additional data came from the Geological Survey and the Economic Research Service of the Department of Agriculture.

Foreign trade data was obtained from the Department of Commerce, Foreign Trade Division publications. R&D data was obtained from the National Science Foundation.

Annual reports of individual companies were obtained from specialized libraries, including the Hicks collection at Purdue University and the Angelo Bruno collection at the University of Alabama, as well as from the collection at Northwestern University.

Data collected relate to production and shipments, manufacturing labor and materials costs, number and size of establishments, number and size of companies, and industry structure - with prices from Sears and other catalogs, and the Bureau of Labor Statistics.

Data was collated by rearranging it so that products that compete with each other can be brought into the same group. For example, using the seven-digit SIC (Standard Industrial Classification), the following selections each create a competing industrial group.

- Processed Vegetables - SIC 20332XX (seventeen XX product codes) and 20372XX (fourteen XX product codes).

- Malted Beverages (beer) – SIC 2082XXX (thirteen XXX product codes).

- Carpets – SIC 227X0XX (nine X0XX product codes).

[26] Because of the lack of detailed data on service sector industries, DINTEC™ necessarily focuses on manufacturing. However the metric equations so developed and validated also apply to the service sector by virtue of the underlying mechanisms being congruent.

- Paints – SIC 28511XX (twenty-two XX codes).
- Cement – SIC 32410XX (seven XX product codes).
- Refrigerators SIC 36321XX (fifteen XX product codes).
- Motor Vehicles NAICS 33611X (two X product codes).
- Televisions SIC 36512XX (eight XX product codes).
- Office Machines SIC 357XXXX (eighteen XXXX product codes).
- Truck Trailers (reefers) SIC 37151XX (three XX product codes), (vans) SIC 37151XX (four XX product codes).
- Pens SIC 39510XX (seven XX product codes plus un-coded gel pens).
- Tire Cords SIC 22960XX (five XX product codes)
- Electric Lamps SIC 36411XX (eleven XX codes)

Precision data collation gave DINTEC™ a scope of about one hundred and fifty products at the seven-digit SIC level. DINTEC™ also includes engineering performance data on tire cords, electric lamps and cement - from various industry sources. These are products where performance from the purchaser perspective is determined more by engineering specification than not.

II. Validating the Metric Equations

Using a standard price index the fundamental equations P = F (p, C, I) and p = G (P, C, I) were validated. Various mechanistic forms for F, C and G were tested against DINTEC™ data to calibrate parameters and obtain good fits with P and p[27].

An unbiased I was found from DINTEC™ separately, using quantils. Producing bias equaling that given in the Boskin Commission's Report validated it. The fundamental equations were then tested and validated using I.

III. Aggregating the Metric; Explaining GDP

GDP is the sum of the value of all final products sold (excluding imports but including exports) so

$$GDP = \sum F N$$

Where N is the number at each price level in a distribution. Therefore once F had been determined in Phase II, the sum to GDP required advanced algebra. The outcome took the form

[27] Econometric methods that rely on admitting variables when they reduce the overall residual variation were not used. Determinative methods were used instead.

$$GDP = H(\sum \sum p, \delta)$$

Where H is a function, ∑∑p is the innovation metric aggregate, and where $\delta << \sum\sum p$. In other words the innovation metric ∑∑p dominates economic growth but is not the sole factor[28]. This was verified using DINTEC™ data representing the manufacturing sector approximate to its real size and results in a new macroeconomic formula

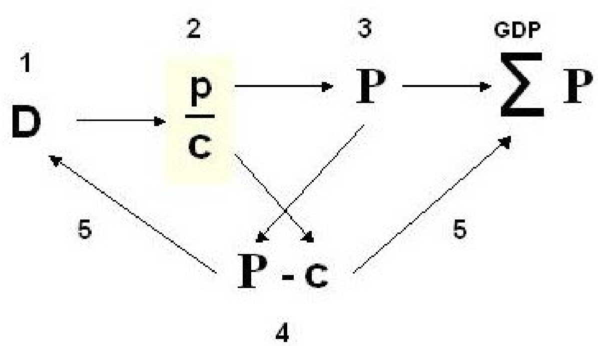
$$\Sigma p + BOT = \lambda \cdot \Psi(GDP, \varepsilon)$$

Its message is that to maintain GDP in the face of an unfavorable balance of trade requires an economy to innovate and increase the aggregated performance of its commerce. The R&D spending necessary to achieve that level of innovation can then be rationally estimated, providing a currently missing policy imperative.

IV. Disaggregating the Metric; Innovation in Firms

Firms must produce products at prices that cover their costs with a profit margin, if they are to expand. And innovation metrics can help with that[29]. Otherwise firms forced into loss by competition contract; are absorbed, or disappear.

The firm level innovation metric is p/c, where c is the unit labor and material cost of production. Firms increase p, and decrease c, by spending money to develop new technologies and to improve old ones[30]. The following pathways show how this links the D of firms' R&D[31] to GDP via the metric p/c.



1- 2. Development spending, D, on diverse activities in entrepreneurial or established firms innovatively increases the market performance, p, of the offering from them and their supply chain and, or, reduces its unit cost of delivery, c.
2. Firms with the highest p/c metric prosper in the face of competition (creative construction) while the weakest risk absorption or disappearance (creative destruction) leading to overall higher market performance.
2 - 3. Higher market performance leads to higher value in price (and therefore GDP).
2 - 4 & 3 - 4. Profit from lower unit cost and, or, higher price allows firms to expand.
4 – 5. Expansion increases the number of higher prices (and GDP) and simultaneously promotes new D.

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[28] Noting that innovation measured by ∑∑p far exceeds total factor productivity (where TFP = $GDP/K^{\alpha} L^{1-\alpha}$ - with K capital, L labor, α constant). Therefore TFP is too small to measure innovation.
[29] Practical examples are explored in a separate document www.techmatt.com/techmatt/CaseBriefs.pdf
[30] Remembering that a firm buys innovation when it purchases from suppliers so its individual development spending increases (p-p′), where p′ is the performance incoming from its supply chain, but its final metric p/c is what protects it from creative destruction by other firms.
[31] Recognizing that development is a highly interdisciplinary craft. And for success it has many co-factors. Among these are many types of innovative activity, including innovative management itself. They all belong within D in TechMatt™ Business Innovation Analysis.

Although R&D has always been intuitively responsible for innovation, and innovation responsible for GDP growth, this has never been numerically demonstrated (despite numerous attempts[32]) and is entirely beyond the scope of standard macroeconomic models that are crippled by interdependency of variables[33].

However DINTEC™ provides an aggregated p/c that shows a very distinctive shape as it rises over five decades, despite its admittedly small sampling. And the corresponding plot of D over the same period shows the same distinctive shape a few years earlier. This displacement of shape eliminates common causal factors that might cause variations simultaneously in both. And the actual shape is encouragingly different for durable and non – durable goods helping to affirm the connectivity between D, p/c and GDP as shown in the Appendix. From this it appears that, although R may act cumulatively (as capital), D is an expense whose impact is delayed.

Productivity

Graphing p/c against D reveals a new innovation productivity measure

$$p/cD$$

Graphs in the Appendix also show that this innovation productivity slowed down for durable goods from the mid – 1970's but increased for non-durable ones from ~1980. Such richness of analysis is far beyond current capability outside of TechMatt™ Business Innovation Analysis. And it may be just what Alan Greenspan predicted would eventually emerge (when in his Delphic mode[34]).

Conclusion

Everyone knows that inventions have enormously improved our quality of life generation after generation as they became purchasable as innovative new products and services. But the commercial nexus between invention and innovation has made it historically hard for outsiders to come up with proper measurement. Consequently TechMatt™ Business Innovation Analysis remains a private sector initiative. Public sectors, such as Universities and Government, cannot currently satisfy the growing need to (a) rigorously understand the origins of economic growth and (b) connect economic growth with Quality-of-Life or Well-being. But TechMatt™ Business Innovation Analysis can do both. The challenge is how to release it into the public domain.

[32] That failed for reasons explained in www.techmatt.com/techmatt/Booz_2005.pdf

[33] In $GDP = K^{\alpha} L^{1-\alpha} TFP$ where K is capital, L is labor, with α constant, TFP is dependently defined as $GDP/K^{\alpha} L^{1-\alpha}$ (see [28]).

[34] The Age of Turbulence, Alan Greenspan, Penguin (2007) - in Chapter 25 The Delphic Future, p 473.

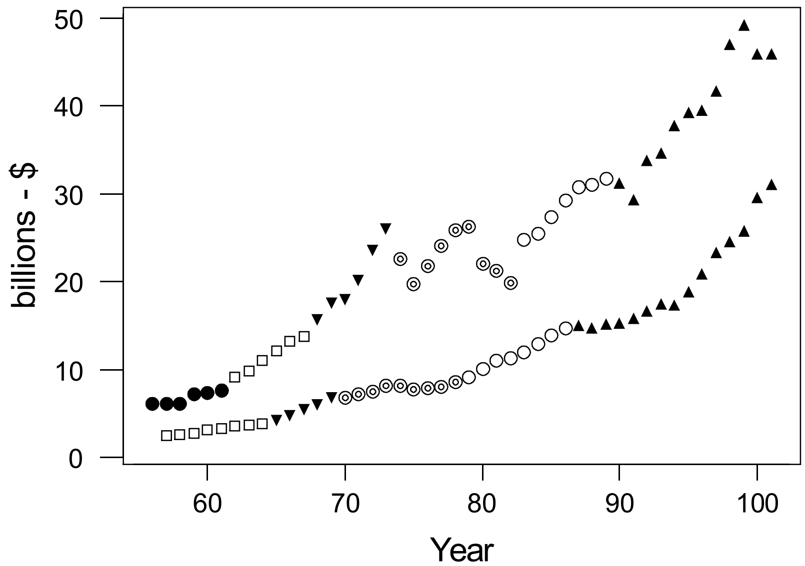
Appendix

Connecting R&D to Innovation Metric (1951 – 2001)

All Durable Goods Firms

Upper - Aggregate Innovation Metric (p/c)

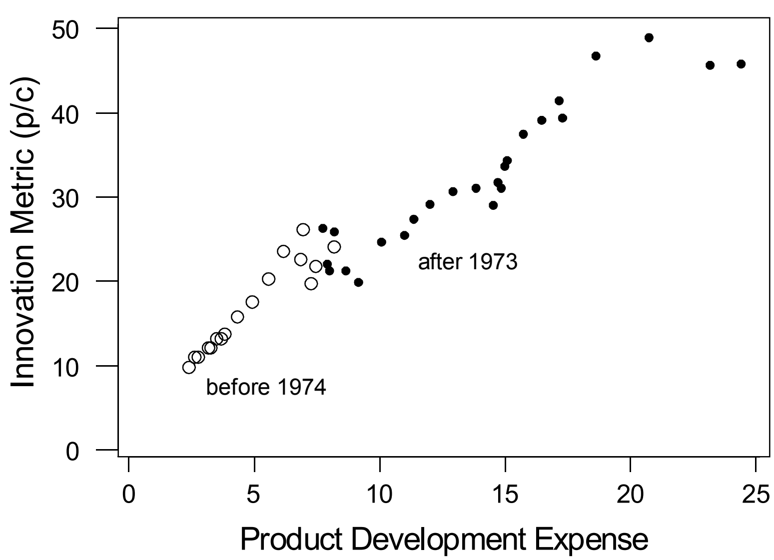
Lower - Product Development Expense



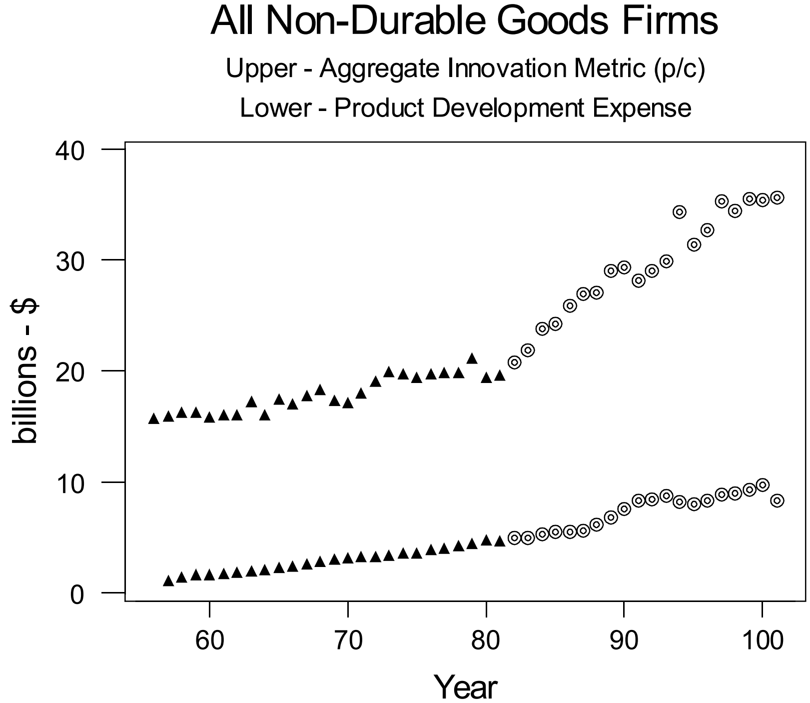
Upper and lower data derive from different sources and have different units, yet show a strikingly similar pattern that can be matched with a 3 - 4 year deferment between cause (lower) and effect (upper) especially after allowing for the oil-crisis instability in p/c 1973~1982.

shift lower data forwards and plot against upper data

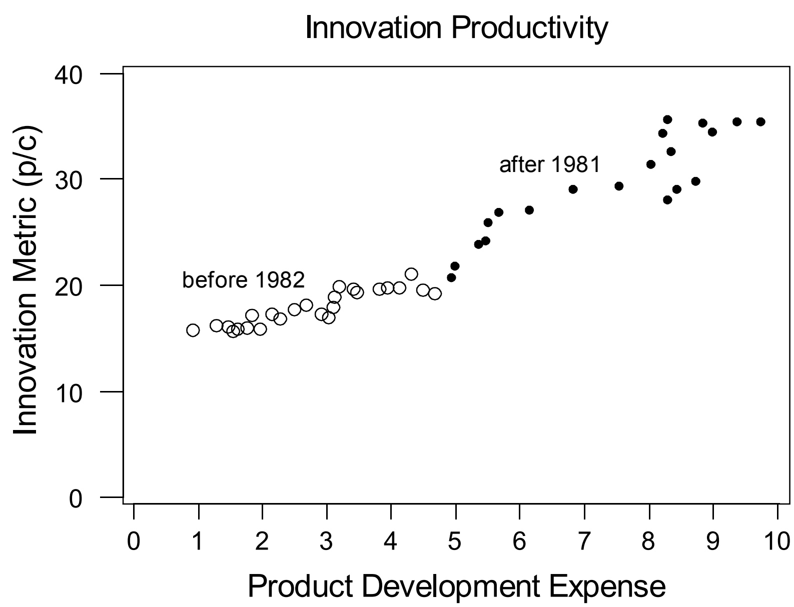
Innovation Productivity



Connecting R&D to Innovation Metric (1951 – 2001), (continued)



Another striking, but different, pattern match for non – durable goods has a shorter ~ 0 – 1 year deferment between cause (lower) and effect (upper).



Connecting Innovation Metric to GDP (1951 – 2001)

The aggregation of innovation metric ΣΣp is plotted against GDP,
where $H'(p) = H(\Sigma\Sigma p, \delta)$
to deliver a 100% explanation of economic growth originating from R&D