How to Measure Innovation in the Products and Services of Firms and Use it to Explain GDP Growth for the Second Half of the 20th Century

Chris J. Farrell

In the 1980's it was thought that the problem of measuring innovation had been solved by Richard Foster's pioneering work. But the practical implementation of his measurement was difficult in most cases, and impossible in others - so only a few iconic examples exist. And in the 1990's Harvard Business School's Clayton Christensen explored a further limitation - innovation often changes the engineering basis of measurement. But by using economic, instead of engineering, data these difficulties are overcome. This opens the door to enumeration by the market and delivers a new innovation tool.

In Part I the history of the Foster S-curve is reviewed and its latest measurement from economic data is discussed. With this metric, innovation is connected to economic growth, GDP. Part II focuses on the firm and shows how the metric can be applied to monitor company-wide innovation and warn of impending threat from competitive innovation implemented elsewhere.

(This paper was originally presented to the U.S. Department of Commerce in May 2007)

Part I – Innovation and Economic Growth

Richard N. Foster, a McKinsey & Co. consultant, wrote one of the best business books of the 1980's. In 'Innovation' he took a theory known simply as 'S-curves', and delivered some excellent practical advice for managing a mature corporation. Not surprisingly, the book cover heralds enthusiastic endorsements from nine prominent CEO's and chairmen of major corporations.

Tires Provide S-curve Data

Tire remnants shed by trucks are a common sight by the side of interstate highways. Their carcasses usually show ribs sticking out. These are tire reinforcements. From the Model - T to the Taurus, Foster took cord performance data and plotted it, figure 1.

On the vertical axis is an engineering measurement of tire cord performance from the Goodyear Company. On the horizontal axis is the total technical effort expended in engineering development to achieve it, as estimated by experts at Celanese, for four generations of cord.

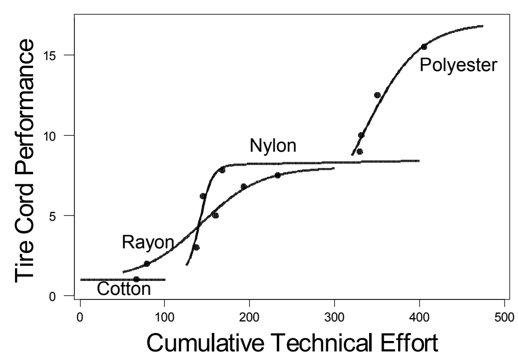


Figure 1 – Engineering sequence of tire cord innovations.

S-Curve Analysis

The Model – T tires were reinforced with cotton fabric. There isn't much you can do to improve it, so the curve is flat. Rayon, however, is a different matter. Wood pulp is dissolved into a thick liquid (called viscose) that is spun into solid fibers. There is plenty of scope here in both chemistry and engineering to make a better fiber for tire reinforcement, and its graph heads upward. Eventually it flattens out because a barrier is reached in the basic chemistry of Rayon. In the meantime Nylon rapidly catches up, and can even surpass, Rayon - displaying the classic S-curve development path. Then comes polyester with a truly superior limit, far above what the earlier fibers could achieve. It dominates, while cotton becomes extinct and rayon heads in the same direction.

Foster used these S-curves to warn companies dependent on products near the limit of their technological growth – at the plateau of the S-curve. By puncturing the delusion of continued prosperity he showed how to act to counter the hidden threats to survival from the next upward S.
.

Toward Innovation Measurement

That engineering development is capable of delivering a series of innovative improvements, each of which drives out its incumbent, each of which strives for an ever-higher performance limit is familiar. But it is unfamiliar, and new, to measure innovation using the performance of the products of such evolving technologies. With twelve data points over six decades it is hardly comprehensive, but it points a way.

Intangible Performance

Tire cords are intermediate goods, steps in the stream of commerce leading from raw materials to finished consumer goods. They are sold business to business and so it is relatively easy to codify their performance in an engineering specification. Indeed, it is the basis on which their sale takes place. However, consumer purchases are made by a personal perception of performance - often involving lifestyle aspiration and other imponderables.

The output of innovation can be quantified by the relative desirability of new products and services to the final purchaser - measured in utils.

Setting aside the fate of a particular company for the moment, when the data for all companies is re-plotted against time, in figure 2, the overall upward drive of innovative performance is very apparent. It was about sixteen fold from the Ford Model –T to the Taurus – whoever was making the cords. Taken together figures 1 & 2 show that performance is an excellent candidate for an innovation metric.

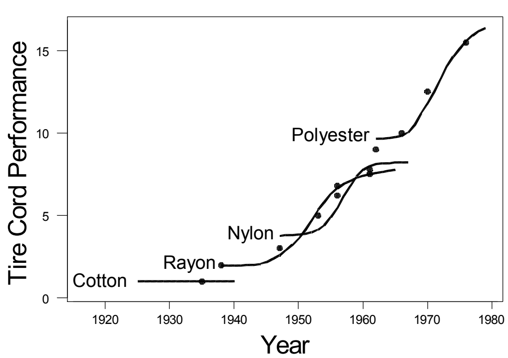


Figure 2 - Upward historical sweep of tire cord innovation.

This challenges the practicality of S-curves dependent on engineering measurement - fine for some intermediate goods, but final products are the ones that contribute to economic growth as expressed in the gross domestic product, GDP and these sell on perception, not engineering fact.

Captured By Price

If consumers perceive advantage in a product they will pay more for it, neatly capturing both engineering and imponderables. But, because price is influenced by other factors – such as competition – it has proven very difficult to extract the performance component of it from price statistics. But this has been achieved recently. The rest of this document uses the new methods. It extracts product performance (as perceived by the purchaser) from economic data and displays it in S-curves, a measure of innovation.

The Example of Pens

If you started school in the 1950's you will have needed a fountain pen (and blotting paper). For your parents it was a steel-nib pen with inkpot - but today we have ballpoints, and no blotting paper or inkpots.

In figure 3 we see shipments of fountain pens increasing from the 1920's to a peak in about 1960 then going into rapid decline, but not disappearing, and then making a slow comeback since about 1980.

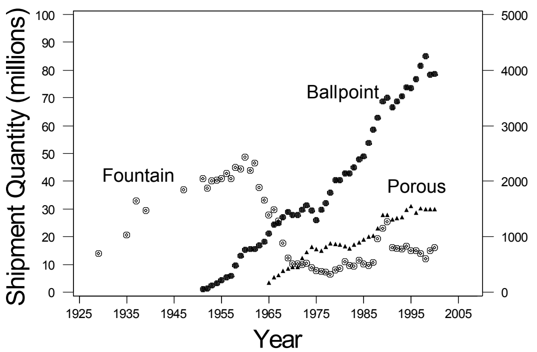


Figure 3 – Quantities of pens showing the fate of the fountain pen as other technologies invade.

The decline was caused by the success of an innovative new ink delivery technology that replaced the nib with a rotating ball – the ballpoint pen. Then another innovative ink delivery technology, using a rigid porous wick, produced pens that joined the fight for consumer preferences with some success.

These innovations can be measured by creating their S-curves from price series using the new methods.

Pen S-Curves Found Using Economic Data

The S-curve for fountain pens, calculated from market data, is shown in figure 4. Annual performance from 1951 provides a very rich picture of innovation. Note that it continues to increase <u>after</u> the start of the market share decline in 1960, with most of the improvement <u>after</u> 1960. This is the era of the status pen – where the cachet of the label is the perception of performance. The innovation is not in the engineering (there is not much actual improvement in these pens) but in creating the perceptions surrounding their purchase and use.

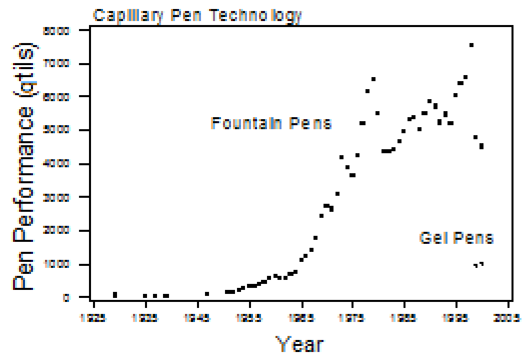
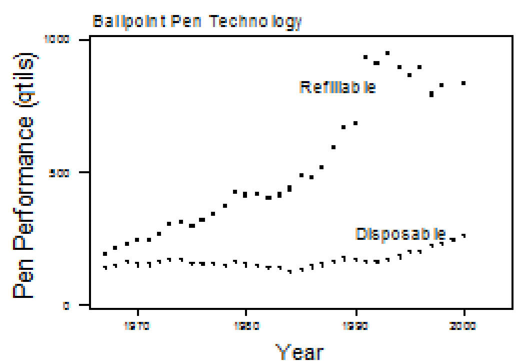
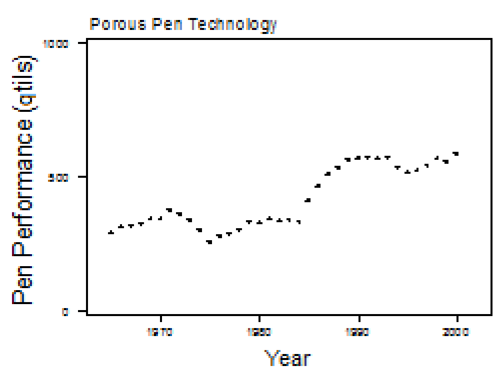


Figure 4 – S-curve for fountain pens, calculated from economic data.

The fountain pen S-curve after about 1975 is driven upward almost entirely by non-technical factors, yet the curve captures them. Intangible factors contribute to GDP just as much as engineering does. The huge dip in performance seen in 1982 was due to the collapse of this luxury market in the recession.





Figures 5 (upper) and 6 (lower) – S-curves for pens with innovative ink delivery technologies. They challenged the fountain pen, and won.

Eight pen categories (some S-curves not shown separately but included) define an industry group and its aggregated pen performance S-curve is shown in figure 7.

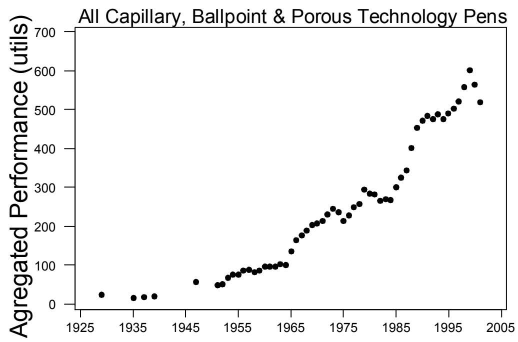


Figure 7 – The S-curve for all the pens taken together as an industrial group.

The richness of data on simple products, such as pens, is what makes the metric possible to extract. And the richness of data on so many products, in addition to pens, makes aggregation possible.

Pen Mightier Than Computer?

Specific economic growth can be illustrated by comparing individual products. For example the S- curves for fountain pens and (home) personal computers, in figure 8. They have broadly similar performance growths with one being driven by intangibles, the other by utility. But their impact on economic growth is quite different, as seen when they are aggregated into their industrial group. PC's belong to office machines – an historical series of innovative products starting with the manual typewriter and

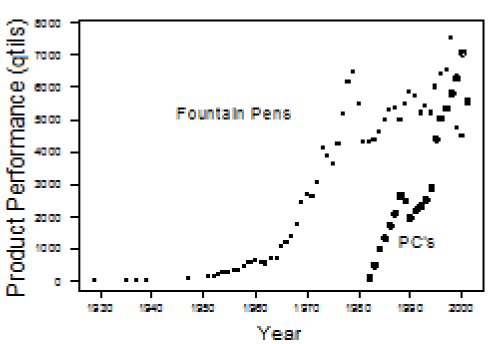


Figure 8 – Comparative S-curves for a pen and a computer.

progressing to the electric and e-typewriters, stand-alone word processors and most recently, the personal computer.

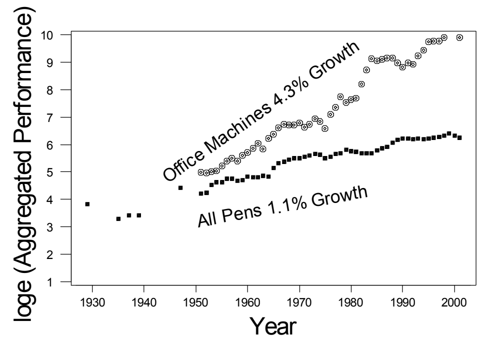


Figure 9 – Comparative innovative growth for two industrial groups. The goods sector grew at an average of 3.3% in the same period.

In figure 9 we see that the performance of the pen group has increased at only 1.1% over time while the office machine group contributes at a growth rate of 4.3%. This is because, despite its performance, the fountain pen has a tiny share of the pen market (compare the left and right hand axes of figure 3), while the PC currently holds a lion's share in office machines.

This S-curve example indicates that economic growth derives from products with fast growing performance on their way to a high limit while capturing a large share of their market. Analyzing data using the new S-curve method should provide means for identifying where investment might best be directed to achieve high growth rate, or perhaps how policy could be framed to stimulate it.

Aggregation To The Goods Sector Level

S-curves can continue to be aggregated to the sector level. Using an extensive database called DINTEC (Data on INnovation, TEchnology and

EConomics) such an S-curve can be approximated, as in figure 10. A question such as 'where are we in innovation?' would certainly have raised concern about the dip in 2001.

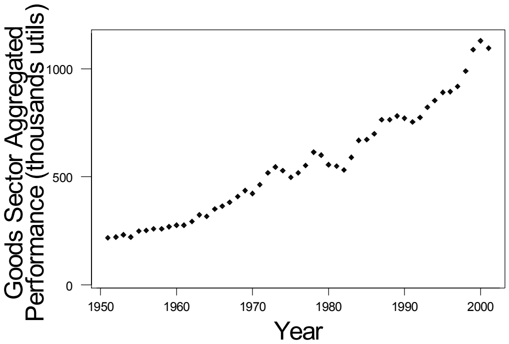


Figure 10 – An (estimate) of S-curve innovations aggregated to the goods sector level can answer the question 'where are we now on the innovation metric?'

Taking the logarithm reveals the underlying innovative growth rates – seen below in figure 11.

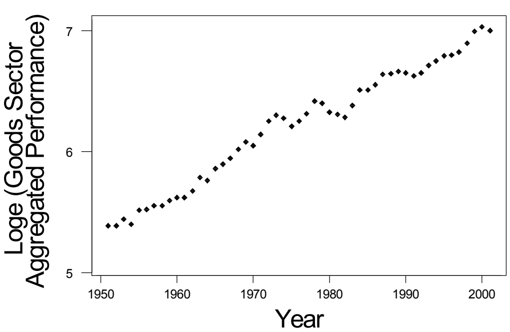


Figure 11 – The slope of this graph gives the growth rates of the aggregated performance of all goods.

Despite the small, though approximately representative, sampling the growth does seem to fall into four general regions (1951-1961), (1961-1973), (1973-1984), (1984-2001) with the fastest growth (1961-1973) and the most recent rate (1984-2001) slower than that. The average growth rate (1951-2001) is 3.3%. Despite the approximations the ultimate potential and power of the S-curve methodology is very apparent.

Aggregation To The Service Sector Level

Service innovation is strongly dependent on the performance of equipment provided from the goods sector. For example, since 1962 the general office has been transformed by innovations in machines - from the typewriters to word processors, from the adding machine to the spreadsheet.

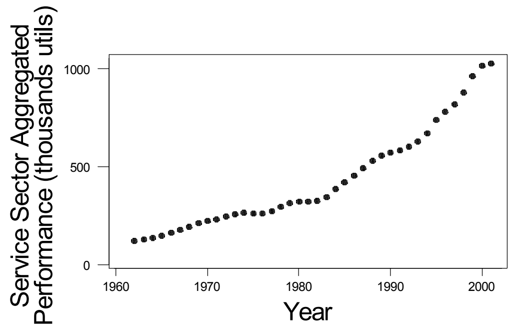


Fig 12 - An (estimate) of S-curve innovation for the private services sector (aggregated with accounting for durability).

Innovation in these, and other, service equipment can also be captured by S-curves and aggregated to assess the performance of the private service industry - remembering that equipment is durable and may be up to twelve years old. Once this is accounted for, the aggregated S-curve for the private services sector is shown (1962 - 2001) in figure 12. The underlying innovative growth rate is 5.2% - well above that for the goods sector.

When innovation is aggregated across the whole economy it drives GDP.

Connecting S-curves to GDP

When innovation S-curves are aggregated across the whole of the goods sector the output to GDP is uniquely determined by H' (with no residual).

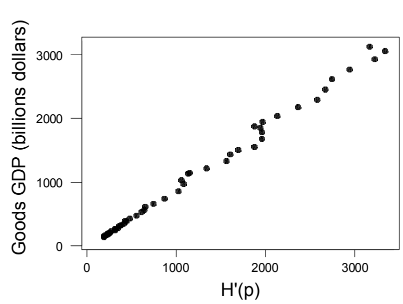


Figure 13 – Using H', aggregated performance can be transformed to GDP – it drives economic growth 1951-2001.

Part II – Innovation and the Firm

Innovation in single product differs from innovation in a whole industry. An individual firm's innovation metric is product performance divided by unit cost of manufacture or (p/c), but p alone characterizes the innovation output of the industry to which the firm belongs.

(Note: This corresponds to the 'race to the top' divided by 'the race to the bottom' in terminology familiar from the British Sainsbury Review of Science & Innovation (2007).)

Fierce Competition in the Beer Industry

Competition in the beer industry provides a striking example of how some firms survived and prospered by it, building on their innovation metric, yet others – such as Falstaff - disappeared.

No one can drink Falstaff beer today but in the 1950's it wasn't far behind Anheuser-Busch in popularity, see figure 14. But by 1970, though its performance was catching up, figure 15, its manufacturing technology (p/c) was falling behind, figure 16.

The criterion for survival is that a company's innovative manufacturing technology (p/c) must be held greater than a certain parameter. This parameter maps out a danger zone. In the next figure it is cutaway to show Falstaff falling into it from 1972 –75. It bounced back in 1976 but it was too late.

With S-curve methods to track innovative progress perhaps they could have done in 1966 what they finally did in 1976, and be here today.

The need to renew profits eroded by competition drives innovation in firms.

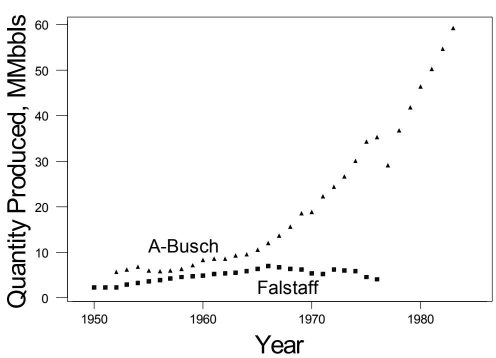


Figure 14 – The popularity of Falstaff peaked in 1966 and then went into decline.

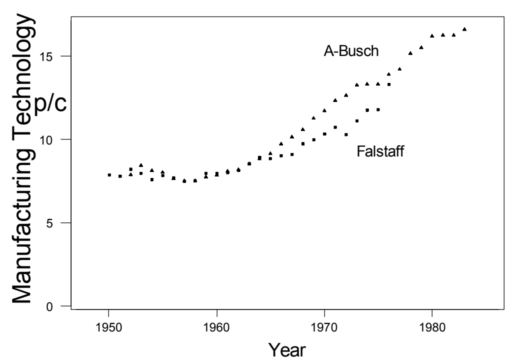


Figure 16 – But Falstaff's manufacturing technology is falling behind.

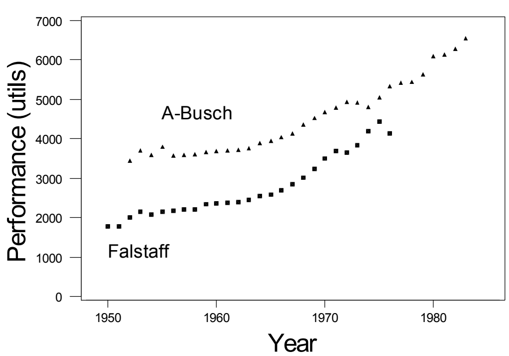


Figure 15 – Falstaff beer raises the perception of its quality and starts to catch up with Anheuser in the 1950' and 1960's.

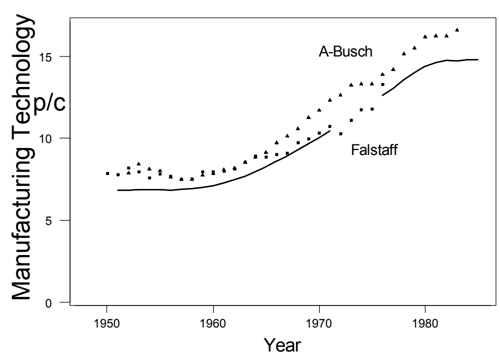


Figure 17 – Falstaff's manufacturing technology heads for the danger zone after 1964 and rides into it in 1972.

Instead Falstaff had to shut its breweries but cleverly wrung the last value from its name by becoming a 'virtual' beer – brewed for the brand owner by Pabst - an end-game ploy that stretched until 2005. In the meantime Anheuser-Busch, who soared above the danger zone did so with some very innovative practices. Among them was brewing at capacity in the slow winter months and storing it in refrigerated warehouses until the summer. In that way they could meet demand not only without risking investment in new capacity, but also because unutilized capacity raises manufacturing cost.

We see in this example that this innovation metric is capturing factors other than just product innovation – and gives rare insight into how competitive innovation works as the ultimate engine of economic growth.

The firms that survive take the products of their better technology forward; those that don't are absorbed or disappear. The economist Joseph Schumpeter aptly called it 'creative destruction' and this study breaks new ground in properly quantifying this important mechanism.

Chris Farrell Ph.D. is a practitioner and a corporate innovator. Since 1988 he has been doing original observational research on the economics of technology innovation.

The research described in this paper is now expanded into a monograph
Innovation in Economics: Missing Pieces
ISBN 978-0-578-45363-7
search for it in Google Books