Microeconomics of Achieving and Sustaining Supernormal Growth in Shareholder Value

Information Theoretic Approach

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“That I may recognize what holds the
Earth together in its inmost essence,
behold the driving force
and source of everything,
and rummage no more in empty words”

Goethe, Faust

As translated by Frederick Reif in Statistical Physics

Definition of Supernormal Returns

"A Supernormal return earns a return that is greater than that earned on investments of equivalent risk. The existence of these excess returns acts as a magnet, attracting competitors to take on similar investments. The excess returns dissipate over time; depending on the ease with which competition can enter the market and provide close substitutes"

Applied Corporate Finance, Aswath Damodaran*, chapter 5*

Thesis: The Source of Supernormal Returns is superior Information Velocity

- Supernormal Returns in Shareholder Value are maintained for greater than 10 years by less than 10% of companies[1]. What is the source of this dismal statistic? Management clearly does not: "behold the driving force and source" of supernormal returns and respond appropriately.
- Thesis: the Necessary and Sufficient Condition ↔ for achieving and maintaining supernormal returns is maintaining Information Velocity much greater than Competitors, defined as:

$$\text{Information Velocity} = \frac{\text{Value Creating Variety Demanded by Market}}{\text{Lead Time to supply that Variety to the Market}}$$

1. *e.g.,* Foster, Richard *Creative Destruction.*

   Christensen, Clay *Innovators Solution,* see App 4 for formula for shareholder value

For Winning Companies: Information Velocity drives Supernormal Returns

- Toyota Motors, Dell Computer, Capital One, Southwest Airlines and others have maintained supernormal returns for more than a decade. It will be shown that this is due to maintaining a rate of Information Velocity superior to competitors in <u>**all**</u> their processes, including product development, manufacturing, marketing, procurement and others.
- **Value Information** injected into the processes at a higher rate results in higher revenue growth rates, and higher operating margins net of capital cost due to:
  - Differentiation and faster innovation
  - Lower operating and capital costs.

What Is the Equation for Information?

- Information= $I \rightarrow$ tells us something unexpected
- The less likely the event, the greater the information I
- Event A has probability p_A and Information I_A ,
  Event B has p_B, I_B ,what is the equation of I ?
- IID: Probability of occurrence of A <u>and</u> B=$P_A P_B$
- We assume that $I_{Joint}(p_A\ p_B)= I_A(p_A)+ I_B\ (p_B)$
- Satisfied only by $\log(p_A p_B)=\log(p_A)+\log(p_B)$ $\therefore$ $I=\log(p)$
- Expectation of Information= $H=\Sigma p_i \log p_i$

  which is Shannon Entropy: Same as Boltzmann[1]

1. see *Statistical and Thermal Physics* by F. Reif, p219 (6.6.24)

Variety of Demand and Market Entropy

Assume a company produces product A and B in quantities $N_A + N_B = D$ per month, in sequences demanded by the market like:

AABABBAABBBABBAB

BBAABABBAAABABBA

BABBABBAAABAABAB, etc.

Essentially there are D Choices per unit of time of either A or B. The number of distinct sequences or "messages" is

$$m = \frac{D!}{n_A! n_B!} = \binom{D}{n_A} = \frac{D!}{n_A!(D - n_A)!}$$

Natural Emergence of Shannon Information

Demand Variety $\rightarrow$ Market Information

- Let $p_A \rightarrow \frac{n_A}{D}$ etc.

- Using Stirling's Approximation (App. 1)

$$\log m \cong -D\sum_{i=A}^{B} p_i \log p_i = DH_{AB} \rightarrow \left(\frac{\text{Choices}}{\text{Unit of Time}}\right)\left(\frac{\text{Bits}}{\text{Choice}}\right) \rightarrow \frac{\text{Bits}}{\text{Unit of Time}}$$

- And for R products from the Market

$$H_R = -\sum_{i=1}^{R} p_i \log p_i \rightarrow \text{Shannon Information of } \textbf{Variety of Demand}$$

$$\text{Information Velocity of Market Variety} = DH_R \text{ bits per unit of time}$$

Market Information and Shareholder Value

- Shareholder Value is driven by Economic Profit (see App 4) :

Economic Profit=ξ=Profit After Tax-Cost of Capital

- Instead of a sequence of products A and B, consider the sequence of their Economic Profits: $\xi_A\ \xi_A\ \xi_B\ \xi_A\ \xi_B\ \xi_B\ \xi_A \ldots$ etc.
- Total $\xi = \sum \xi_j$

Let $p_j = \frac{\varepsilon_j}{\varepsilon}$ = probability that the jth product contributes ε, then per App 3:

$$D\log\varepsilon = D\sum_{j=1}^{R}\frac{\varepsilon_j}{\varepsilon}\log\left(\frac{\varepsilon_j}{\varepsilon}\right) + D\sum_{j=1}^{R}\frac{\varepsilon_j}{\varepsilon}\log\varepsilon_j = D\left(H_R + E\log\varepsilon_i\right)$$

$$D\log\varepsilon = \begin{pmatrix}\text{Information on}\\ \text{Value of Variety}\end{pmatrix} + \begin{pmatrix}\text{Information on Avg}\\ \text{Value per Product}\end{pmatrix}, \text{ e.g., if } \frac{\varepsilon_j}{\varepsilon} = \frac{1}{R}$$

$$D\log\varepsilon = \quad D\log R \quad + \quad D\log\varepsilon_j$$

Maximizing Shareholder Value: Entropy of Complexity

- To maximize Economic Profit ξ, we can maximize log ξ .
- The first term is the information on value of variety.
- The second term is the Kelly criterion[1] for log-optimal investment, and is maximized if total internal investment is apportioned among the R offerings in proportion to ξ_i
- ξ_i declines[2] as a R increases (e.g., Case Study 7)
- Hence a maximum value of

$$\mathrm{MAX}(\log\varepsilon) = f\left(\frac{d\varepsilon}{dR}\right) \text{ exists for some value of } R$$

- Total Information Velocity of Demand= $D\left(H_R + E\log\varepsilon_i\right)$

1Cover, *Information Theory*, Chapter 6

2.George and Wilson, *Conquering Complexity In Your Business,*

Impact of Customer Lead Time on Required Information Velocity of Supply

$$\text{Information Velocity}_{\text{Demand}} = D\left(H_R + E\log\varepsilon_i\right) = \frac{\left(H_R + E\log\varepsilon_i\right)}{\left(\frac{1}{D}\right)} \text{ bits per unit of time/choice}$$

$$\text{Natural Period/unit of product} = \tau_N = \left(\frac{1}{D}\right) \text{ units of time/choice}$$

- But if customer will accept lead time t= $\tau_c > \tau_N$ for a choice to be satisfied, then required information velocity of the process is reduced to:

$$\text{Info Velocity}_{\text{Supply}} = \frac{\left(H_R + E\log\varepsilon_i\right)}{\tau_c} \text{ bits per unit of time/choice}$$

  for a unit of product of product supplied to the customer

- To use this equation, we must apply Little's Law of lead time

High Internal Process Entropy results in high WIP, and long Lead Time τ

- Little's Law[1]: Lead time τ of any process

$$\tau = \frac{\text{Units of Work In Process=WIP}}{\text{Completion Rate in Units/Time=D}} = \text{Lead Time}$$

- Little's Law leads[2] to $\text{Entropy}_{\text{IntProcess}} = D^2\log(\text{WIP})$

$$\text{WIP} = e^{D^2\left(H_{\text{IntProcess}} + E\log W_i\right)} \text{ units of Work In Process}^3$$

$$\text{Lead Time to supply demand} = \tau = \left(\frac{1}{D}\right) e^{D^2\left(H_{\text{IntProcess}} + E\log W_i\right)} \text{ in units of time}$$

1. Hall, *Queuing Methods*, Hopp *Factory Physics*
2. George, *On the Entropy of Business Processes*, George, Patell, et al, *On the WIP of a Business Process*
3. See appendix 2 and 3 for a derivation and an expression for $H_{\text{IntProcess}} + E\log W_i$

Internal Process Entropy =log(WIP) Creates Waste: Lowest Cost Occurs when Information Velocity of Supply=Information Velocity of Demand

- **General Motors Way:** High Changeover Cost
  - Demand: AABABBAABBBABBAB=16 bits per month
  - Supply: AAAAAAAABBBBBBBB=2bits per month
  - 2 changeovers: results in 8 units of WIP, entropy=$\log_2 8$,high non value add costs due to warehouses for inventory, scheduling cost , scrap, rework, obsolescence.
- **Toyota Way:** Near Zero Changeover Cost
  - Demand: AABABBAABBBABBAB=16 bits per month
  - Supply: AABABBAABBBABBAB=16 bits per month
  - ~16 changeovers with WIP$\rightarrow$1,entropy=$\log_2 1=0$, and non value add costs $\rightarrow$0.
  - Lowest cost occurs if Information Velocity of Supply=Demand (App6) ,

1 See Lean Six Sigma Pocket Tool book by George,Price and Rowlands for a discussion of the four step rapid setup method

The Corporation is an Information Engine

$$\text{Information Velocity} = \frac{\text{Variety of Market Demand/Unit time}}{\text{Lead Time to Supply that Variety}}$$

$$\text{Information Velocity} = \frac{(H_R + E\log\varepsilon_i)}{e^{D^2(H_N + E\log W_i)}/D} = \frac{\text{Bits}}{(\text{Units})/(\text{Units/Time})} = \frac{\text{Bits}}{\text{time}}$$

$$\text{Information Velocity} = D(H_R + E\log\varepsilon_i)e^{-D^2(H_N + E\log W_i)}$$

$$\text{SuperNormal Returns} \rightarrow \begin{pmatrix}\text{Increase Market} \\ \text{Valued Entropy}\end{pmatrix} \begin{pmatrix}\text{Decrease non value add internal} \\ \text{Variety and Waste, Case Study7}\end{pmatrix}$$

Preview of Process Entropy

- In appendix 2 we show that process entropy is proportional to logW where W is the amount of inventory in process.
- The purposive thrust of the Toyota system drives $W \rightarrow 1$,logW and waste $\rightarrow$ zero
- Note that in a Carnot Engine, entropy and waste also vary as logW. (appendix 5)

Adding Information to a Process: A Manufacturing Example

WIP per Product[1] $=W_i \geq \left(\frac{AS_iD}{(1\text{-}X_i\text{-}P_iD)}+A\right)$, Total WIP $=W==NW_i$ where:

S=Setup Time, A=Number of steps in the process

P=Processing time per unit, X=Defect % Rate

N=Number of different internal components produced to satisfy Market H_R

Let Probability a product is the $i^{th}=p_i=\frac{W_i}{W}=\frac{1}{N}$ then

$$\text{Process Entropy} = \text{Log}W=H_N+E\log W_i = (\log N) + \log\left(\frac{AS_iD}{(1\text{-}X_i\text{-}P_iD)}+A\right)$$

$$\text{Log}W = \begin{pmatrix}\text{Product}\\ \text{Complexity}\end{pmatrix} + \begin{pmatrix}\text{Process}\\ \text{Waste}\end{pmatrix}$$

- Thus by adding information to the process by reducing N, S, X,P, A we increase the velocity, reduce the entropy, and the waste of the process like a heat engine.

1.The equation of WIP derived by M.George and J. Patell (Stanford GSB)

Smart Company Accelerates <u>All</u> <u>3</u> Sources of Information Velocity

- **Lean Six Sigma:** Adding information to reduce variability, lead time τ and *explicit* waste in products and processes.
- **Conquering Complexity:** Adding information to reduce τ and *implicit* waste in products and processes.
- **Fast Innovation:** Adding information to Marketing and R&D to reduce time-to-market, increase differentiation growth and margins.
- The company that adds quality information at the fastest rate wins.

The fast.......................................the slow.......................................the result!

Feedback to mgeorge@georgegroup.com

1. Is the thesis that Information Velocity is the driver of supernormal returns important? Irrelevant?
2. Has anyone taken this approach before?
3. Do you know anyone who would have an interest in this presentation?
4. If worthy of publication, what journals would be likely candidates?
5. How can the presentation be improved in:
   - Content
   - Order

Case Studies of the Predictive and Strategic Power of Information Velocity

1. Henry Ford: *Process Entropy*
2. Alfred Sloan vs. Henry Ford: *Market Entropy*
3. Toyota vs. GM: *Market and Process Entropy*
4. AMD vs. Intel: *Process Entropy*
5. Dell vs. Compaq: *Process Entropy*
6. United Technologies vs. Ford: Process Entropy
7. International Power Machines: Process Entropy
8. Whirlpool vs. Maytag: Market and Process Entropy
9. IBM vs. IBM: Market Entropy

Isn't Information Velocity an Obvious Way to Maintain Supernormal Returns?

- That 90% of companies cannot maintain supernormal returns argues to the contrary.
- We assert that maintaining a significant gap in Information Velocity is the **<u>necessary</u> <u>and</u> <u>sufficient</u>** $\leftrightarrow$ condition to maintain supernormal returns.
- Let us test this Shareholder Value Imperative with empirical examples.

Case Study 1:Value Creating Variety: Information Supplied By Economic Profit (EP) Distribution of the R Products in the Market

- Products with negative ξ add no value information and are eliminated
- H_R is the variety needed to generate Economic Profit
- In 1921, the Model T accounted for 90% of the economic profit of industry
- $H_R \cong 0$ bits, $H_N = 0$, $E \log W_i = \log A \cong 2$

Comparative Examples of Information Speed: Henry Ford vs. GM

- Ford only produced one model from 1908-1927, hence each workstation only produced 1 item, N=1, complexity=0, and hence there was no setup, S=0. Thus per App 2A

$$H_{IntProcess} \cong \log(1) + \log\left(\frac{(0)DA}{(1\text{-}X\text{-}PD)} + A\right) = \log A$$

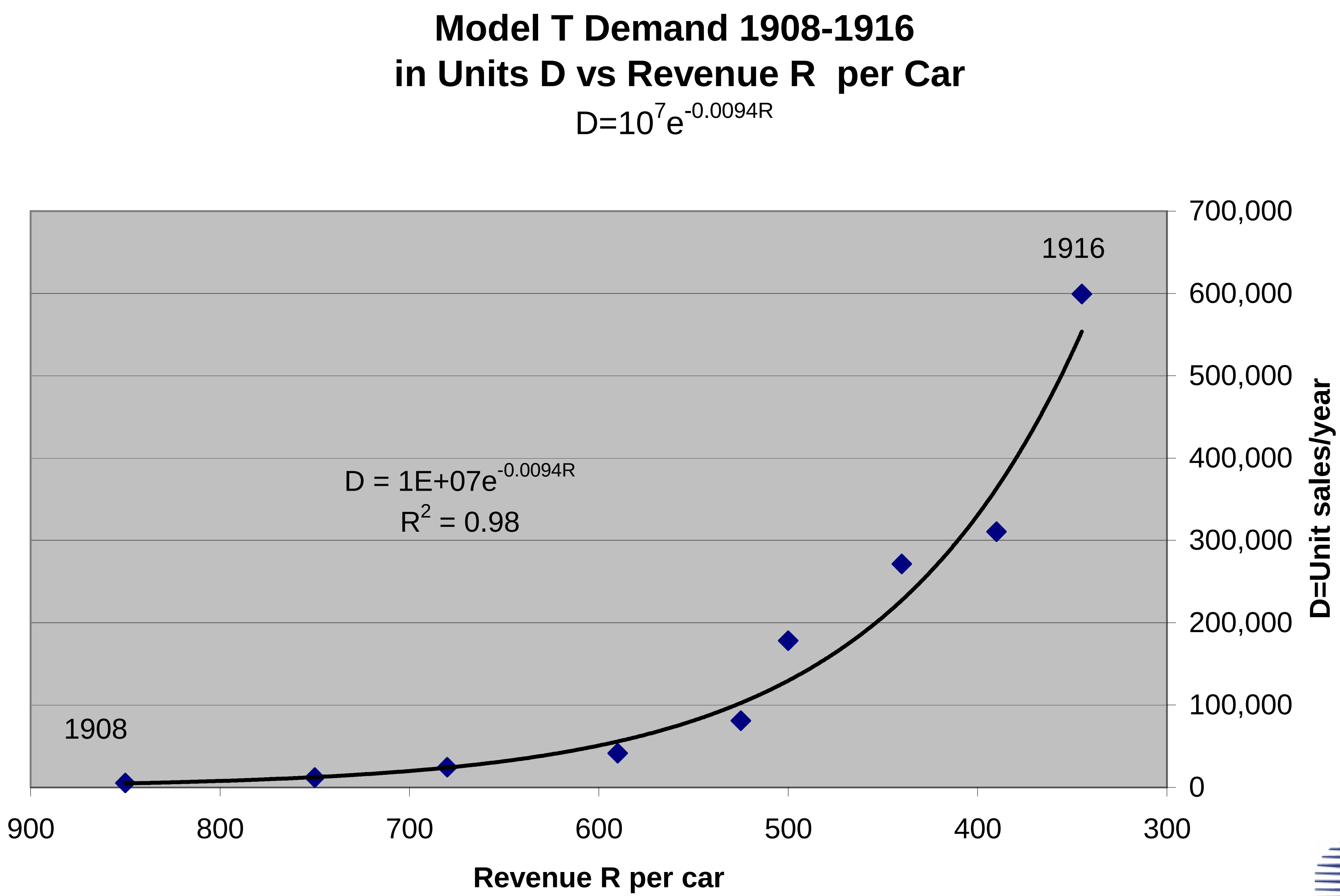
$$H_R = \log(1) = 0$$

- Hence

$$\text{Information Velocity} = \frac{0}{e^{\log A}} = \frac{0}{A} = 0$$

- Henry Ford fell victim when H_M market demand increased from near zero for utility transportation to near logR, the variety offered by GM. Ford's share falling from 65% in 1921 to 0% in 1927, transferring Ford's supernormal returns to GM

Henry Ford Exploited an $H_m \cong 0$ Market With Low Process Entropy and Economies of Scale dD/dt



Case Study 2.Alfred Sloan:
General Motors Market Entropy Increased From 0 to Log$_2$5

- Internal Process entropy very large compared to Ford due to long setups S, poor quality X, long process paths A, and lack of standardization N. Per App 2A:

$$H_{IntProcess} \cong \log N + \log\left(\frac{SDA}{(1\text{-}X\text{-}PD)} + A\right) = \log N + \log\left(A\left(\frac{SD}{(1\text{-}X\text{-}PD)} + 1\right)\right)$$

$$H_{IntProcess} \cong \log N + \log A + \log\left(\frac{SD}{(1\text{-}X\text{-}PD)} + 1\right)$$

- Third term very large. General Motors built 5 distinct models and a multitude of submodels hence HR>log5>Ford=0.

$$\text{Information Velocity} = \frac{\log_2 5 +}{\left(\frac{NASD}{(1\text{-}X\text{-}PD)} + NA\right)} > 0 = \text{Henry Ford}$$

- Hence, despite inefficient operations, because HM~log5,GM enjoyed supernormal returns from 1924 to 1984. This model also describes Compaq and most other companies.

Case Study 3:Toyota Vs. GM:
The Variety of GM and the Efficiency of Henry Ford

- Offers a product line comparable to General Motors, i.e., H_R>log5+ ,builds multiple products hence N≠1, but S→0+ε where ε can be made arbitrarily small at modest cost by continuous application of the Four Step Rapid Setup[1] method, etc. Hence according to App 2:

$$H_{\text{IntProcess}} \cong \log N + \log\left(\frac{(0+\varepsilon)DA}{(1\text{-}X\text{-}PD)} + A\right) \cong \log N + \log A$$

$$\text{Information Velocity} = \frac{\log 5+}{NA} >> \frac{\log 5+}{\left(\frac{NASD}{(1\text{-}X\text{-}PD)} + NA\right)} = \text{General Motors}$$

$$\text{Toyota} \rightarrow NA \approx 10^4 << 10^6 \approx \left(\frac{NASD}{(1\text{-}X\text{-}PD)} + NA\right) \rightarrow GM$$

- Thus the Information Velocity of Toyota is at least an order of magnitude larger than GM, driving GM market share from 51% to 25% and transferring supernormal returns to Toyota. Toyota External Market entropy comparable to GM, Toyota internal Process entropy approaching Henry Ford. Toyota model is also characteristic of Dell.

1 See George et al, *Lean Six Sigma Pocket Toolbook*

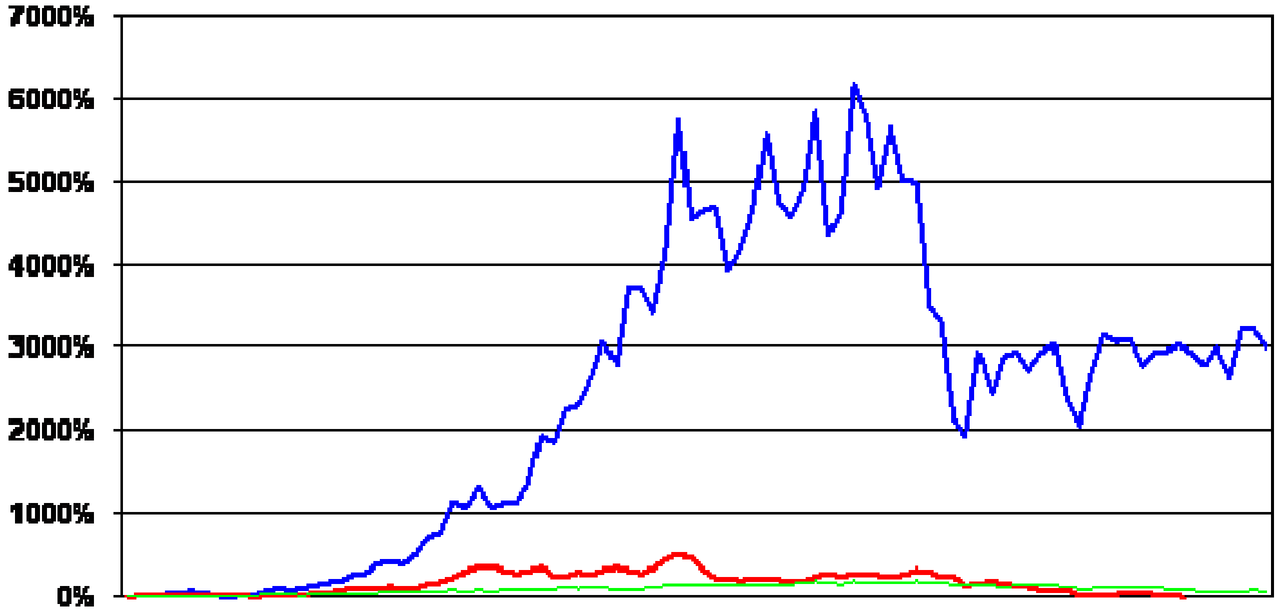
Case Study 4:Intel vs. AMD
Information Velocity: The Giant Killer

- Intel enjoyed supernormal returns until it failed to supply the 64bit X86 chip, while AMD succeeded. AMD had never enjoyed supernormal returns, but superior information velocity reversed their roles.

Case Study 5: Dell vs. Compaq Ten Year Return

Dell = 1500% vs. Compaq = 0%

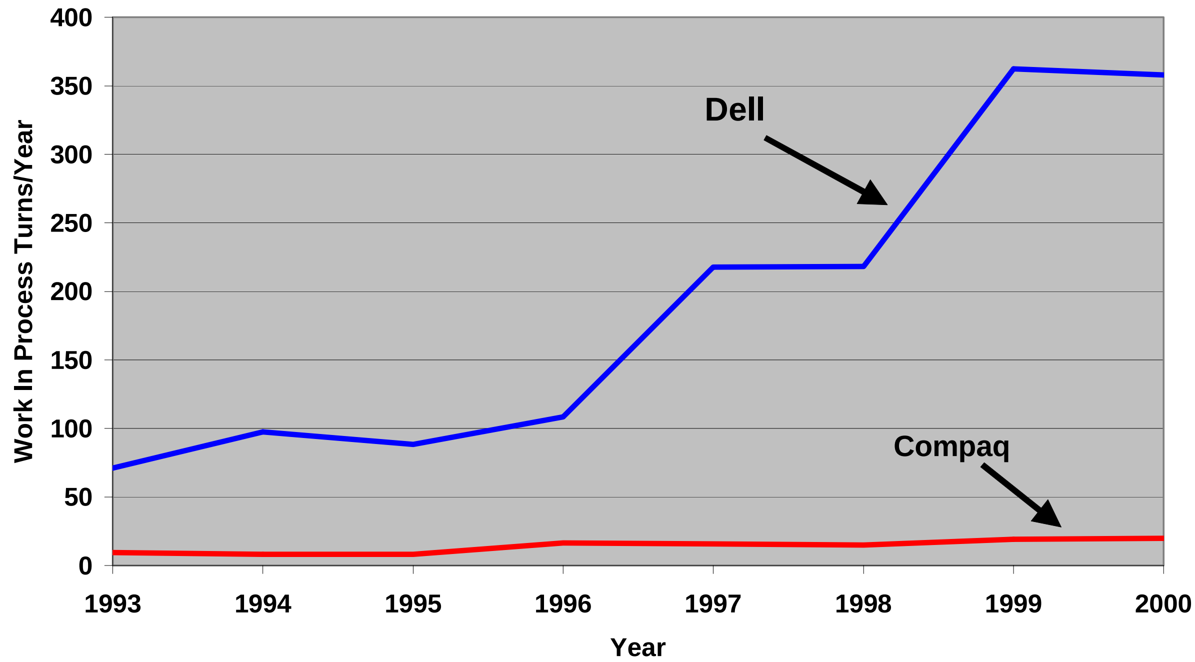
- Compaq created most innovations (high H_R), but had high process entropy. Dell quickly copied Compaq products and had comparable H_R, but very low process entropy hence much higher Information Velocity.



Dell Information Velocity 35 Times Greater Than Compaq

- WIP turns=1/τ, hence Dell Operational lead time is 35 times smaller than Compaq. H_M is comparable for both firms$\therefore$, Dell information velocity is 35 times greater than Compaq.

Process/Business Model Innovation by Dell
Compaq fails to copy Dell…and is destroyed!



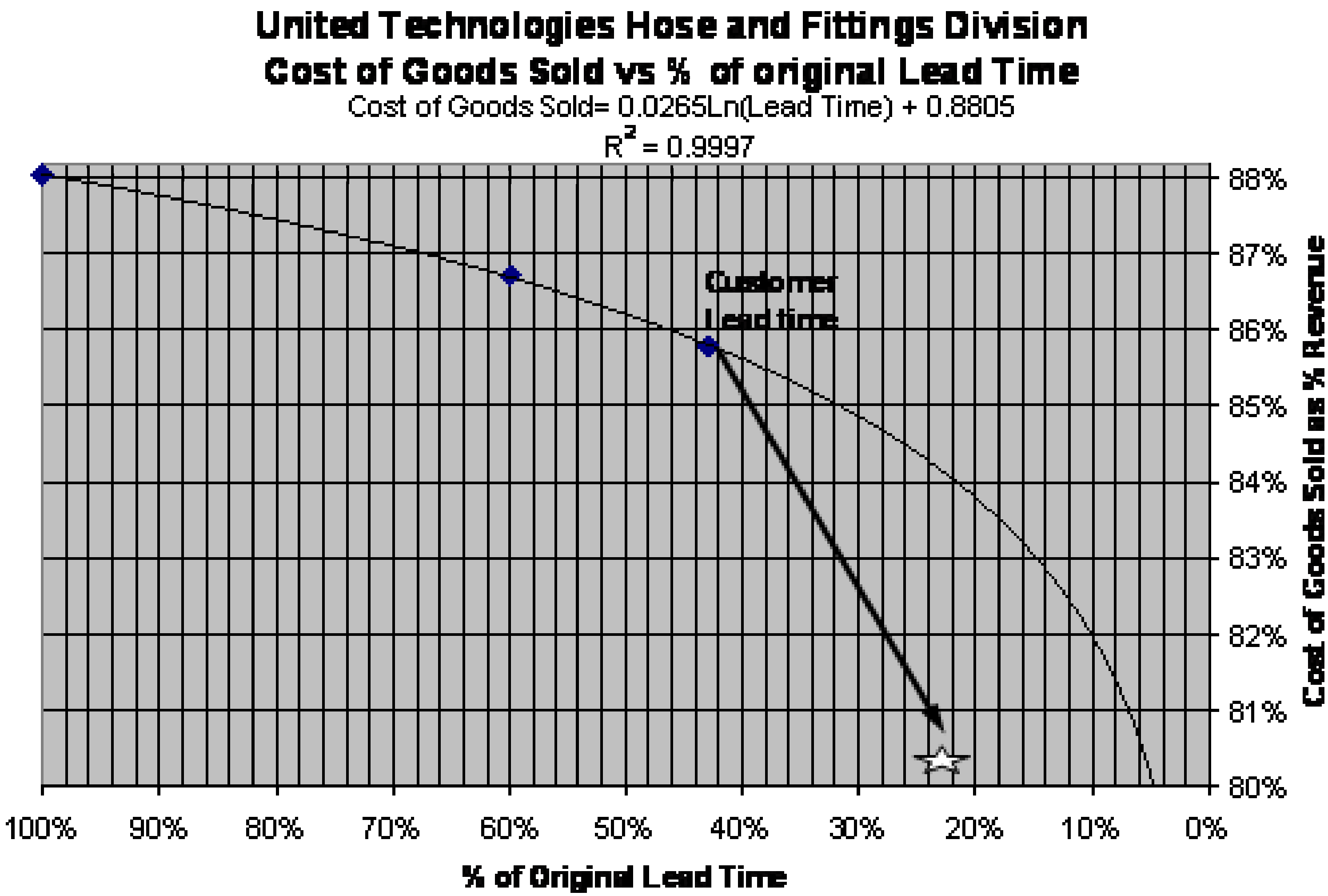
Case Study 6: The Waste Free Process: Why Companies Must Reduce Process Lead Time τ<<T=Customer Lead Time

- The perfect process has no waste cost, which is typically 10-20% of revenue: N,S,X,P,A are wastes to be reduced.
- Waste eliminated when all cost is value add
- In the perfect process $\tau \rightarrow$Total Value Add Time
- Material is passed in lot size 1(setup time S=0, defects X=0%) from value add to value add tasks $A_0 < A$, for a given R, internal Complexity is reduced from N to N_0
- Waste$\rightarrow\delta$ as:

$$\text{Entropy} = \log(\text{WIP}) = \log\left(\frac{\text{NSDA}}{\text{1-X-PD}} + \text{NA}\right) \rightarrow \log(0 + N_0 A_0) \rightarrow 0 + \varepsilon$$

Case Study in the Approach to a Waste Free Process

United Technologies Automotive Information Velocity 4 Times That of Ford Climate Control



..Resulting in Supernormal Returns and Increasing Shareholder Value by 225%

Results of Entropy Reduction Lean Six Sigma:

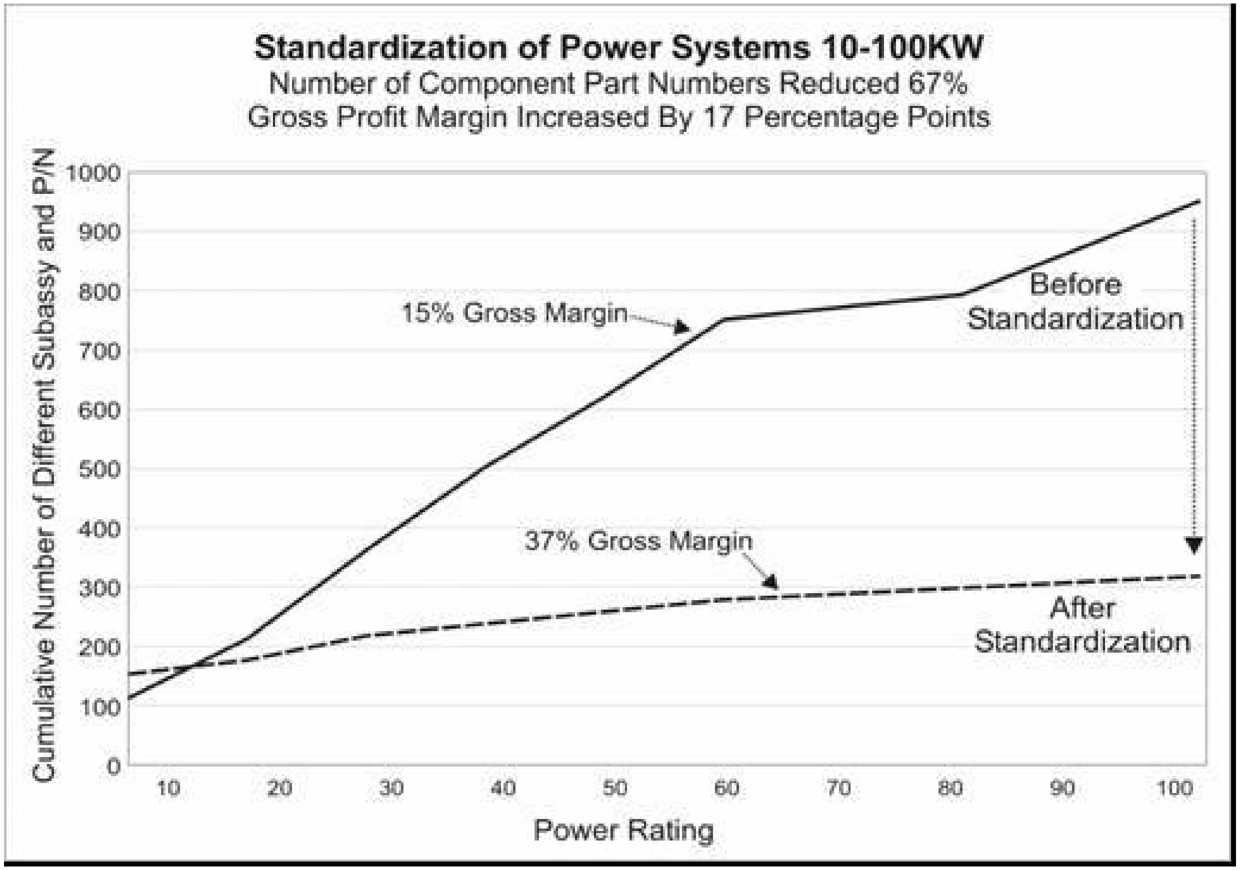
United Technologies Automotive Hose and Fittings

Customer Quality	
Quality Performance (External CTQ)	From 3σ to 6σ (regained Ford Q1)
On-Time Delivery	From 80% to >99.7%
Lead Time	From 14 Days to 2 Days
Inspection	Moved from Full Final Inspection to In-Process Inspections

Financial Results	
Operating Margin	From 5.4% to 13.8%
Capital Turnover	From 2.8 to 3.7
ROIC	From 10% to 33%
Enterprise Value	Increased 225%
EBITDA	Increased 300%
Economic Profit=ROIC% - WACC%	From –2% to 21%
Work-In-Process Inventory Turns	From 23 to 67 Turns per Year

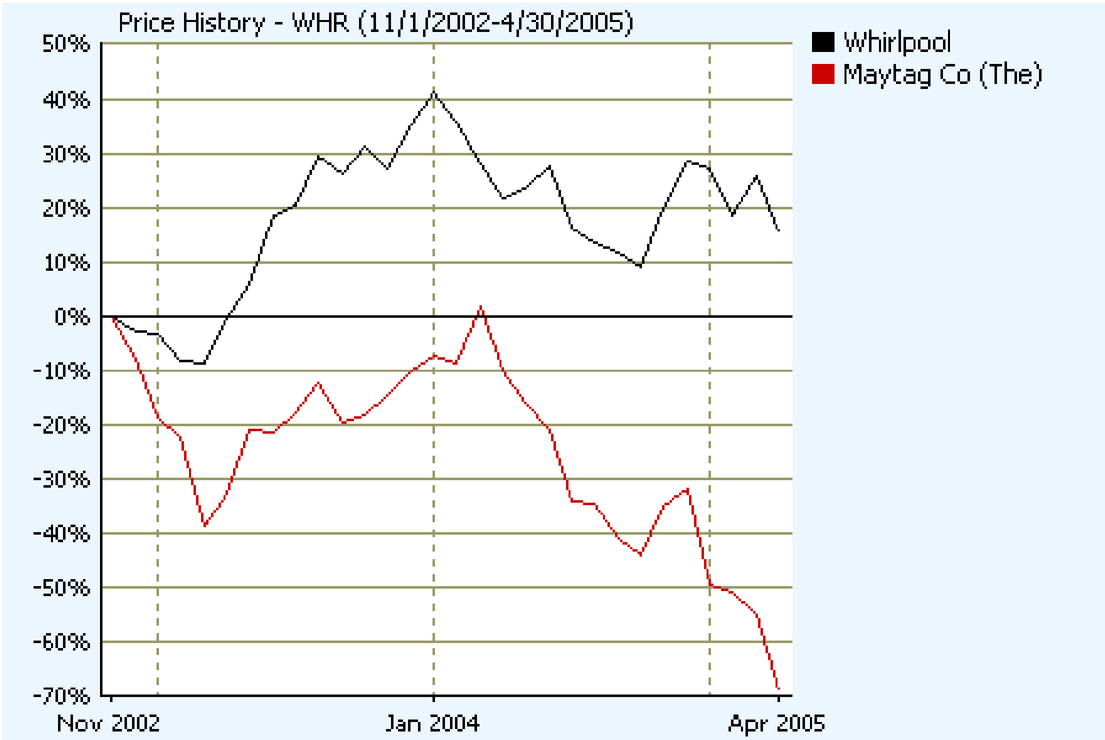
Case Study 7: Reduction of Process Entropy by eliminating “Non Value Add Internal Variety” (ref page 15)

International Power Machines produces Uninterruptible Power Supplies in a variety of power ratings, each of which had its own part numbers By standardizing the designs, the number of different part numbers was reduced from 960 to 320, entropy reduction eliminated waste=22% of revenue



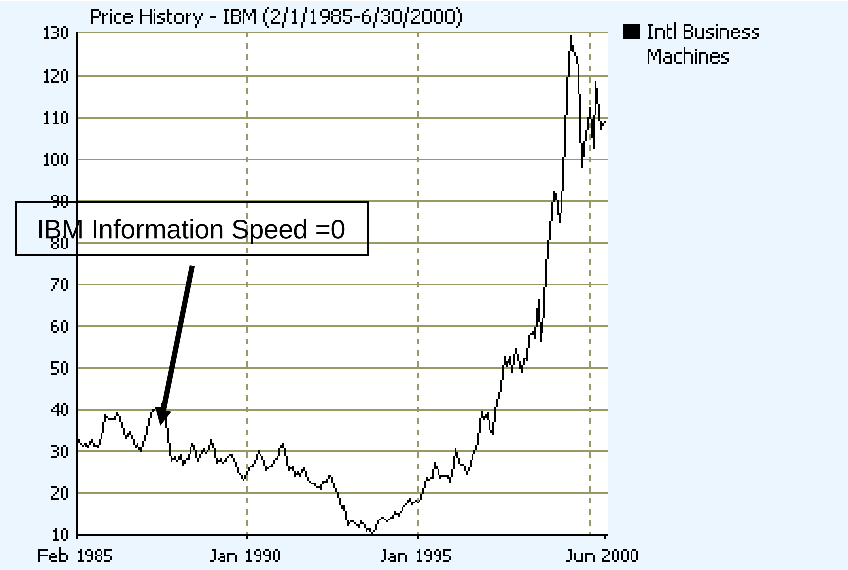
Case Study 8:Maytag vs. Whirlpool
to the victor go the spoils!

- Maytag focused on reduction of the denominator of Information Velocity, reducing $H_{IntProcesses}$ in an effort to reduce cost and improve quality. Whirlpool chose a balanced approach, emphasizing highly differentiated innovation (dramatically increasing H_M) as well as lower $H_{IntProc}$. The duel ended with Whirlpool acquiring Maytag.



Case Study 9:IBM vs. IBM
Riches to Rags to Riches

- IBM maintained supernormal returns from 1922 to well into the 1980's. In the 1990's, IBM management was in denial about the decline of main frames due to PC, Windows, UNIX servers, routers etc. The rate at which information was received by IBM management fell below the rate at which the information was transmitted by the market. Only by radical increase of Information Velocity to reposition the company (e.g. attack EDS, acquire PwC, withdraw from Hardware) to positive Economic Profit businesses was IBM able to return to supernormal returns.



Empirical Conclusions

- **Thesis:** A company which maintains a significant gap in Information Velocity will maintain supernormal returns as has Toyota and Dell. Had Compaq, IBM, Maytag, Ford Climate Control, GM, Henry Ford, and Intel applied management resources to monitor ***and*** accelerate Information speed, they would have maintained supernormal returns without interruption.
- **Corollary:** If a competitor wishes to acquire and maintain the supernormal returns of a competitor, it must first generate a gap in information velocity.

Academic Input

- George Judge, Cal Berkeley
- Amos Golan, American Univ
- David Wolpert, NASA, Santa Fe Inst
- UT Austin
  - Sergey Z Levendorskiy
  - Svetlana Boyarchenko
  - Patrick L Brockett
  - Maxwell B Stinchcombe
  - Vince Geraci

Table of Appendices

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5. Entropy Reduction in Carnot Isothermal Compression Thermodynamics of a Business Process
6. What Is the Maximum Number of Unique and Acceptable Demand Sequences given the Shareholder Value Constraints of the Corporation?

App 1. Demand Variety and Shannon Entropy $\sum p_i \log p_i$

from page 8, $M=\dfrac{D!}{n_A!n_B!}=\dfrac{D!}{n_A!\left(D\text{-}n_A\right)!}$,$p_A=\dfrac{n_A}{D}$ etc

Note that:

$$\log_2 M = \ln M \log_2 e = 1.44 \log M$$

$$\log_2 M = 1.44\left(\log D! - \log n_A! - \log\left(D-n_A\right)!\right)$$

using Stirling's formula(D>100/month): $\log D! \cong D\log D - D$

$$\log_2 M = 1.44\left(D\log D\text{-}D\text{-}n_A\log n_A + n_A - \left(D-n_A\right)\log\left(D-n_A\right) + \left(D-n_A\right)\right)$$

$$\log_2 M = 1.44\left(D\log D\ \text{-}n_A\log n_A - \left(D-n_A\right)\log\left(D-n_A\right)\right)$$

but $D=(D\text{-}n_A)+n_A$,hence

$$\log_2 M=1.44\left((D\text{-}n_A)\log D\ n_A\log D\text{-}n_A\log n_A-\left(D-n_A\right)\log\left(D-n_A\right)\right)$$

$$\log_2 M=-1.44\left((D\text{-}n_A)\log\left(\frac{D\text{-}n_A}{D}\right)+n_A\log\left(\frac{n_A}{D}\right)\right)$$,multiplying by $\dfrac{D}{D}$, *obtain*:

$$\log_2 M=-1.44D\left(\left(\frac{D\text{-}n_A}{D}\right)\log\left(\frac{D\text{-}n_A}{D}\right)+\left(\frac{n_A}{D}\right)\log\left(\frac{n_A}{D}\right)\right)$$

$$\log_2 M=-1.44D\left(\left(\frac{D\text{-}n_A}{D}\right)\log_2\left(\frac{D\text{-}n_A}{D}\right)+\left(\frac{n_A}{D}\right)\log_2\left(\frac{n_A}{D}\right)\right)=\log_2 M=1.44D\sum_{i=A}^{B} p_i \log p_i$$

App 2
Entropy of a Business Process

- Starting with Little's Law: $$\tau = \frac{\text{Units of Work In Process=WIP}}{\text{Completion Rate in Units/Hour}} \equiv \text{Lead time in hours}$$
- We derive the velocity equation via inversion. Define

  R=Revenue per Unit

  C=Avg Cost per unit at a Workstation or Activity in the process including Material Mfg and SG&A Overhead, and Cost of Capital

  A= Number of workstations or Activities which comprise the process

  W=Work In Process (WIP) in units

  ξ =R-CA=dollars of Economic Profit per unit

  D= Units per hour completed
- Next, we obtain a relationship similar to the inverse of Little's Law: τ=W/D. The process improvement tools reduce WIP W and hence increase velocity.
- We differentiate the velocity equation to obtain an equation of acceleration. The effective mass of the process is shown to be W^2, which results from the agreement of two independent derivations, one based on Feedback Control Theory, the other on Enthalpy.

$$\text{Force} = W^2 \frac{d^2P}{dt^2} = WD\frac{dP}{dt} - \left(D\left(\frac{dW}{dt}\right) - W\left(\frac{dD}{dt}\right)\right)P$$

App 2
Entropy of a Business Process (Cont.)

- Since Force=Acceleration/Mass, by integrating the force of process improvement between an initial low process velocity $v_{initial}$ (high WIP) and a desired higher final process velocity v_{final},(low WIP) and obtain an expression for the energy needed to accelerate process velocity:

$$\text{Energy}=\text{U}=\frac{1}{2}\text{D}^2\mathcal{E}^2=(\text{Economic Profit/Month})^2$$

$$\text{d(Work)}=\text{dU-U}\frac{\text{dW}}{\text{W}},$$

$$\text{Work}=(\text{U}_{\text{final}}\text{-U}_{\text{initial}})-\int_{\text{Winitial}}^{\text{Wfinal}}\mathcal{E}^2\text{D}^2\frac{\text{dW}}{\text{W}}\rightarrow\mathcal{E}^2\text{D}^2\text{logW for constant }\mathcal{E}^2\text{D}^2$$

$$\text{logW=H+ElogW}_{\text{i}}\text{ per Appendix 3}$$

$$\text{Work}=\mathcal{E}^2\text{D}^2(\text{H+ElogW}_{\text{i}})\rightarrow\text{TS, T}\rightarrow\mathcal{E}^2\text{,S=Entropy=D}^2(\text{H+ElogW}_{\text{i}})$$

App 3
The Entropy of Variety

- **WIP W**
  - For two different products $W=W_1+W_2$
  - $\log W=\log(W_1+W2)=H(W)+Ex(\log W_i)$
  - logW=Entropy of Variety +Entropy of Process
  - $W=e\ H(W)+Ex(\log W_i)$
- **Economic Profit ξ**
  - For two different products $\xi = \xi_1 + \xi_2$
  - $\log \xi = \log(\xi_1 + \xi_2) = H(\xi) + E(\log \xi_i)$
  - $\log \xi$ =Entropy of Variety + Entropy of Efficiency

App 3
Derivation of Impact of Variety (Cont.)

$$\log W = \frac{W_1 + W_2}{W} \log W = \frac{W_1}{W} \log W + \frac{W_2}{W} \log W = -\frac{W_1}{W} \log \frac{1}{W} - \frac{W_2}{W} \log \frac{1}{W}$$

$$\log W = -\frac{W_1}{W} \log \frac{1}{W} - \frac{W_2}{W} \log \frac{1}{W} + \left(\frac{W_1}{W} \log W_1 - \frac{W_1}{W} \log W_1 \right) + \left(\frac{W_2}{W} \log W_2 - \frac{W_2}{W} \log W_2 \right)$$

$$\log W = -\left(\frac{W_1}{W} \log \frac{W_1}{W} + \frac{W_2}{W} \log \frac{W_2}{W} \right) + \frac{W_1}{W} \log W_1 + \frac{W_2}{W} \log W_2$$

We can denote the probability that the jth item of WIP is p_j where:

$p_j = \frac{Wj}{W}$ and obtain:

$$\log W = -\sum_{j=1}^{N} \frac{Wj}{W} \log \left(\frac{Wj}{W} \right) + \sum_{j=1}^{N} \frac{Wj}{W} \log Wj$$

$$\log W = -\sum_{j=1}^{N} p_j \log p_j + \sum_{j=1}^{N} p_j \log W_j = H(W) + E(\log Wi)$$

$W = e^{H(W)+E(\log Wi)}$

and for $pj = 1/N, Wj = W/N = ASD/(1\text{-}X\text{-}PD)$ from App2:

$\log W = \log N + \log\{ASD/(1\text{-}X\text{-}PD)\} =$ entropy of variety+entropy of process

App3 $H_{IntProcess}$ Manufacturing Entropy

- It has been shown1 that, for a manufacturing process:

$$H_{IntProc}=\log W=-\sum_{j=1}^{N} p_j \log p_j+\sum_{j=1}^{N} p_j \log W_j = H(WIP)+E(\log WIP)$$

$$W=e^{H_{IntProc}}$$

$H_{IntProc}$=Entropy of WIP+Expectation(log of Process Variables)

$H_{IntProc}$=Entropy of Variety+Entropy of Process

N=total number of different products produced

D=total demand per unit of time for all N products

W=Total WIP=$\sum_{j=1}^{N} W_j$, W_j=WIP of the j^{th} product, $\therefore, p_j=\frac{W_j}{W}$

per[1] $W_i \geq \left(S_iD/(1-X_i-P_iD)\ +A\right) \rightarrow$ ProcessVariables

S=Setup Time, A=Number of steps in the process

P=Processing time per unit, X=Defect % Rate

1. App 4.

App 4
Market Information of Shareholder Value

- Assuming constant growth of g% per year in Economic profits, the perpetual annuity formula yields the shareholder value for any company based on its current year's (year zero) Economic Profit:

$$\text{Shareholder Value} = \text{BookValue} + \frac{\text{Economic Profit}_0}{\text{WACC\%} - g\%}$$

  - Book Value = Total Assets-Total Liabilities (assuming Economic Profit≥0)
  - Economic Profit = ξ=(ROIC% - WACC%)(Invested Capital)
  - ROIC = Return on Invested Capital = (Profits after Tax)/(Invested Capital)
  - Invested Capital (IC)= Total Assets – Current Liabilities
  - Assets= Inventory + Accounts Receivable + Fixed Assets + Cash& Securities
  - Liabilities= Accounts Payable + Notes Payable + Accruals
  - WACC = Weighted Average Cost of Capital ~ 10%
  - g% = Growth in Economic Profits per year or Revenue if ROIC is fixed
- Those goods/services for which ROIC%>WACC% have positive Economic Profits will add to the shareholder value. On the other hand, the goods/services for which ROIC<WACC will destroy shareholder value.

1. McTaggert, Stern, Copeland, op cit
2. For finite and supernormal valuation formulae, see J Fred Weston, *Takeovers, Restructuring*... These formulae avoid the singularity at WACC=growth

App 5
Entropy Reduction in Carnot Isothermal Compression

1st Law of Thermodynamics

Addition of Heat =dQ=dU(Internal Energy)+PdV(work done by system)

Ideal Gas: $dU=c_V dT$, T=Temperature, PV=RT,P=Pressure, V=Volume

2nd Law of Thermodynamics

$$\Delta\text{Entropy}=\int_{\text{initial}}^{\text{final}} \frac{dQ}{T} = \int_{\text{initial}}^{\text{final}} \frac{c_V dT+PdV}{T}, P=\frac{RT}{V} \text{ and for isothermal } dT=0$$

$$\Delta\text{Entropy}=\int_{\text{initial}}^{\text{final}} R\frac{dV}{V}=R\left(\log\left(V_{\text{final}}\right)-\log\left(V_{\text{initial}}\right)\right)$$

and is negative since $V_{final}<V_{initial}$

An amount of energy equal to the Temperature times the Entropy is drawn from the hot source, and $\geq$ that amount is expelled as waste to the cold sink.

The lower the process Entropy, the lower the waste

Internal Process Entropy and Little's Law

- Consequence of Little's Law: Compute the energy needed to increase velocity V of a process using Force from App2

(W=WIP=Work In Process. ξ=Economic Profit, D=Demand, units/hour)

$$\text{Energy}_{V_i \rightarrow V_f} = \mathcal{E}^2 D^2 \left(\log W_{\text{final}} - \log W_{\text{initial}}\right),$$

$$\mathcal{E}^2 = (\text{Profit})^2 \rightarrow \text{Temperature}$$

$$W \rightarrow \text{Volume}$$

$$\text{Energy}_{V_i \rightarrow V_f} \rightarrow (\text{Temperature})(\text{Entropy}_{\text{final}} - \text{Entropy}_{\text{initial}}) = T\Delta S$$

same as the work necessary to reduce entropy of an ideal gas in isothermal compression(app5)

Adding Information to accelerate the velocity of a process is equivalent[2] to Subtracting Entropy rather than adding mechanical energy

1. *Microeconomics of Achieving and Sustaining Supernormal Growth in Shareholder Value – Information Theoretic Approach*
2. L. Brillouin, Science and Information

Thermodynamics of a Business Process[1], a Few Consequences of Little's Law

$$\text{Mass} = W^2, \text{Velocity} = V = \frac{PD}{W}, \text{Kinetic Energy} = \frac{1}{2}MV^2 = \frac{1}{2}\mathcal{E}^2 D^2$$

note: Kinetic Energy of a Business Process is not velocity dependent

$$\text{Pressure} = \frac{\text{ForceXDistance}}{\text{AreaXDistance}} = \frac{\text{Energy}}{\text{Volume}} = \frac{\mathcal{E}^2 D^2}{2W},$$

k_P (Boltzmann Constant of Process) $= D^2$

$$\text{Brownian Velocity} \approx \left(\frac{k_P T}{M}\right)^{\frac{1}{2}} = \left(\frac{D^2\mathcal{E}^2}{W^2}\right)^{\frac{1}{2}} = \frac{D\mathcal{E}}{W} = V$$

1. *Microeconomics of Achieving and Sustaining Supernormal Growth in Shareholder Value – Information Theoretic Approach*

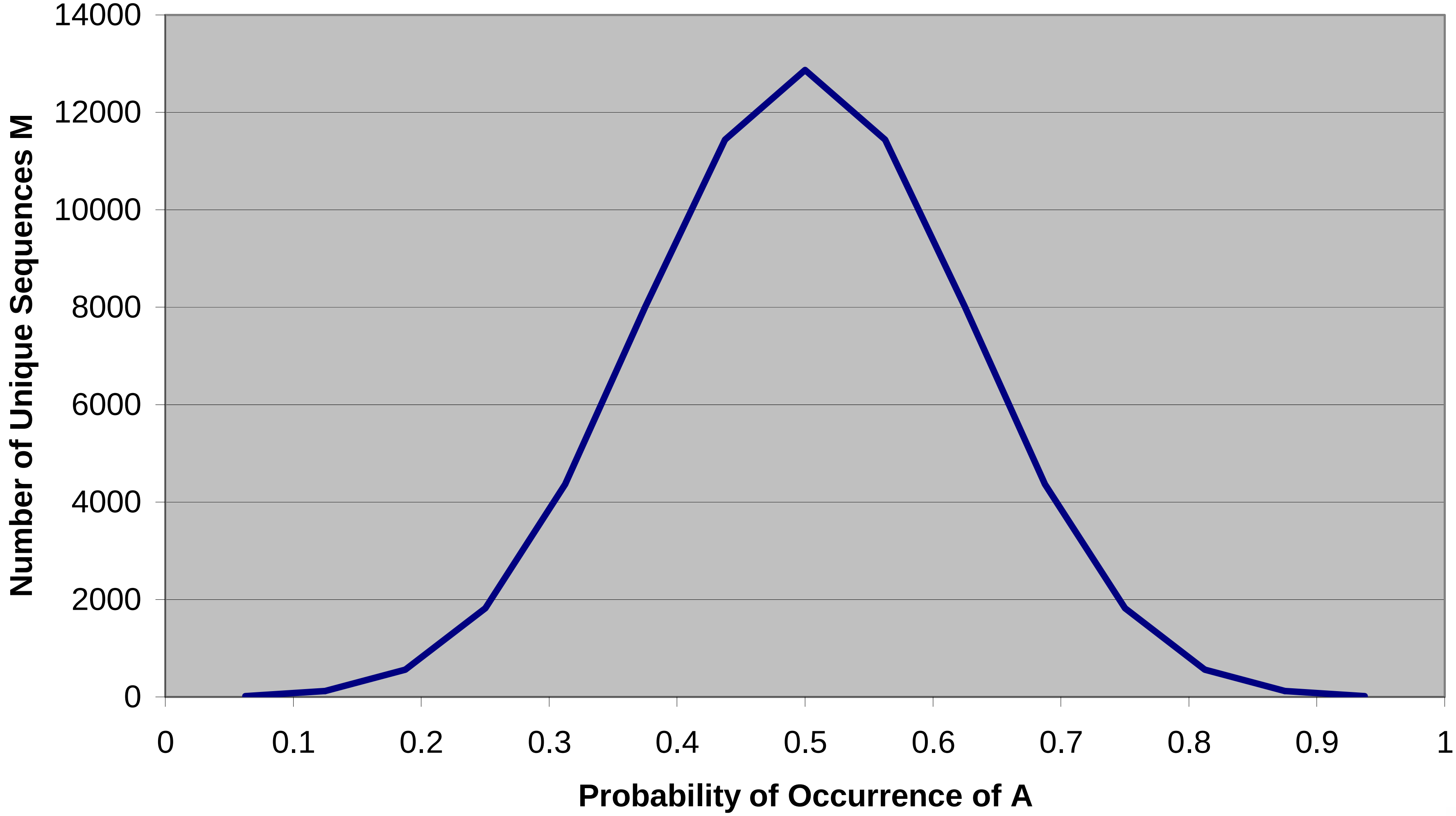
App 6: What Is the Maximum Number of Unique and Acceptable Demand Sequences Given the Constraints of the Corporation?

- The number of unique sequences is

$$m = \frac{D!}{n_A!\,n_B!} = \binom{D}{n_A} = \frac{D!}{n_A!\,(D - n_A)!}$$

- A sample graph and spreadsheet is attached.
- However, not all unique sequences are acceptable to the company. Some products have Economic Profit ξ_i near WACC and create little value. A sequence that does not generate the required ξ_{AVG} needed to support shareholder value cannot be included.

Number of Unique Sequences M vs. Probability of Occurrence of Product A, D=16 Per Month



Spreadsheet

prob of A	A	B	A!	B!	16!	m=16!/A!B!
0.06	1	15	1	1.30767E+12	2.09228E+13	16
0.13	2	14	2	87178291200	2.09228E+13	120
0.19	3	13	6	6227020800	2.09228E+13	560
0.25	4	12	24	479001600	2.09228E+13	1820
0.31	5	11	120	39916800	2.09228E+13	4368
0.38	6	10	720	3628800	2.09228E+13	8008
0.44	7	9	5040	362880	2.09228E+13	11440
0.50	8	8	40320	40320	2.09228E+13	12870
0.56	9	7	362880	5040	2.09228E+13	11440
0.63	10	6	3628800	720	2.09228E+13	8008
0.69	11	5	39916800	120	2.09228E+13	4368
0.75	12	4	479001600	24	2.09228E+13	1820
0.81	13	3	6227020800	6	2.09228E+13	560
0.88	14	2	87178291200	2	2.09228E+13	120
0.94	15	1	1.30767E+12	1	2.09228E+13	16

What Is the Maximum Number of Unique and Acceptable Demand Sequences Given the Constraints of the Corporation?

- Shareholder Value is driven by (see App 4) :
  - Economic Profit= ξ =Profit After Tax-Cost of Capital
- Let us assume that we make D products per month, n_i of which are the i^{th} type
- Assume N different products, and that each of the i^{th} product types generates
- ξ_i= (Economic Profit)$_i$ =(Profit After Tax)$_i$ –(Cost of Associated Capital)$_i$
- Two Constraints on the Corporation

$$0.\ \text{Acceptable messages per month} = m_c = \left(\frac{D!}{n_1! n_2! \ldots . n_N!} \right)$$

subject to two constraints :

$$1. \sum_{i=1}^{N} n_i = D,\quad 2. \mathcal{E}_{avg} \leq \frac{1}{D} \sum_{i=1}^{N} n_i \mathcal{E}_i$$

The $\mathcal{E}_{avg}$ constraint reduces the large number of *possible* sequences in 0.

to smaller number of *acceptable* sequences.

Calculated as a function of the values of n_i using Lagrange Multipliers

Maximum Number of Acceptable Sequences Results When the Probability of a Product's Profit Follows the Canonical Distribution

Constrained messages per month $= m_C = \left(\dfrac{D!}{n_1! n_2! \ldots\ldots n_N!} \right)$

and using Stirling's Approximation we find:

$$\log m_C = -D \sum_{r=1}^{N} \frac{n_r}{D} \log\left(\frac{n_r}{D}\right) = -D \sum_{r=1}^{N} p_r \log p_r$$

*w*hich is maximized subject to constraints 1 and 2 by the Canonical Distribution:

$$p_r = \frac{e^{-\beta \varepsilon_r}}{\sum_{r=1}^{N} e^{-\beta \varepsilon_r}}$$

See Tribus, *Thermostatics and Thermodynamics*, pp 75-80 for computation of β

About George Group

Since 1986, we have created an unsurpassed record of successful partnerships with Global 2000 companies and governmental agencies. We have built the thought-leading practices in the critical areas of value creation:

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We deliver both the strategic insight and operational execution required for our consulting clients to surpass their growth, speed and cost goals. Further, we create the essential capability and cultural transformation for our clients to achieve and sustain superior shareholder returns.

We invite the CEO concerned with growth in shareholder value to read the executive overviews of our groundbreaking books and compare alternatives.

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