NOTE TO FILE:
Garvin H Boyle
Dated: R1:170502 R2:170504 R3:170514

On Three Measures of Efficiency

Frontispiece

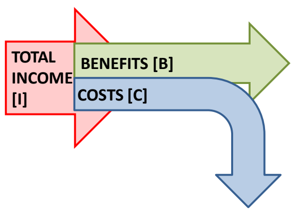
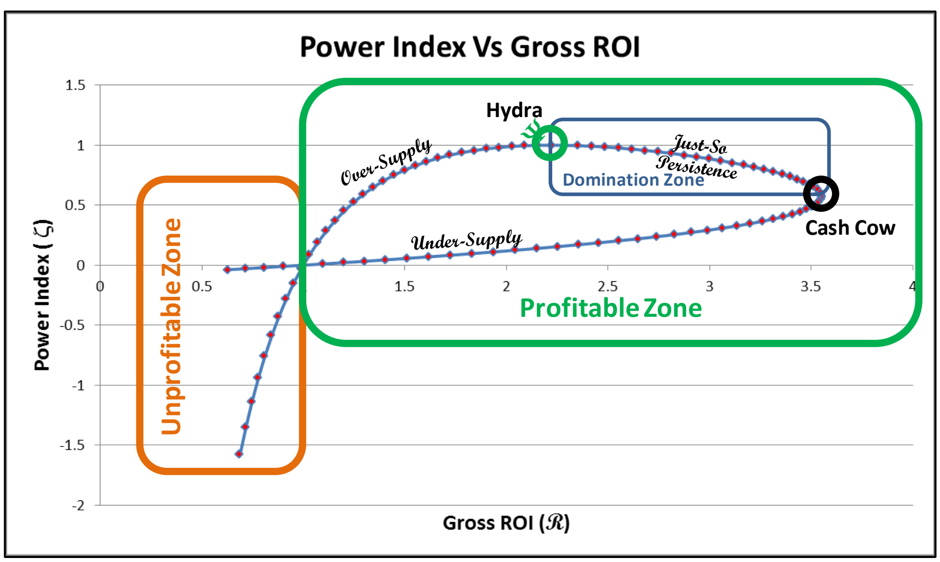


Table 01 – Definitions.

Definitions of Flows		
I = Income or Gross Returns	C = Costs or Investments	B = Benefits, Profits, or Net Returns
Definitions of Efficiency Formulae		
$\eta \equiv \frac{B}{I}$	$R \equiv \frac{I}{C}$	$N \equiv \frac{B}{C}$

Table 05 – Table of conversions of efficiency formulae.

	η	ℛ	𝒩
η	$\eta = \eta$	$\eta = \frac{R-1}{R}$	$\eta = \frac{N}{N+1}$
ℛ	$R = \frac{1}{1-\eta}$	$R = R$	$R = N+1$
𝒩	$N = \frac{\eta}{1-\eta}$	$N = R-1$	$N = N$



Contents

1 - References

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2 - Background

At Ref A I investigated the various ways the three related concepts of income, costs and benefits (denoted as I, C and B respectively) could interact when converted to power and efficiency. Goldilocks are always the result. The fundamental relation I = B + C is the source of the curious nature of these Goldilocks curves. In this context, efficiency was defined as $\eta \equiv B / I$, as was used by H.T. Odum in his Ref B article.

That investigation led me to wonder about three different definitions of efficiency, and how they relate. The $EROI \equiv I / C$ (Ref C) was tested in place of η in some of my spreadsheets, and I found that there was a close connection between the two. Both could be associated with Goldilocks curves.

Further reading about efficiency brought to my attention the great variety of opinions and practices around the word "efficiency". For example, at Ref D the "efficiency ratio" in economic terms is expenses / revenue (i.e. efficiency ratio = C / I), which is the inverted reciprocal of what you would expect, considering the analogies from physics.

1 - Purpose

To investigate the relationship between three different definitions of efficiency: as discussed by Odum (η), EROI (Energy Returned on Energy Invested), and NEG (Net Energy Gain).

3 - Discussion

3.1 - Definitions I, C and B:

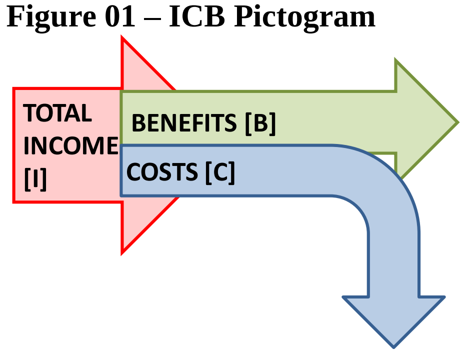
In this section I represent symbols in square parentheses to distinguish them from capitals used for lexical purposes. My intent is that this discussion will be applicable to any situation in which a flow of a conserved quantity (such as energy or money) is used to generate profits, or is used to accomplish some useful purpose. I.e. I intend it to be very general, in the spirit of the Ref A NTF:

- [I] represents the total flow of (e.g.) energy or money. [I] also represents the concept of incoming resources.
- [C] represents the investments or costs associated with the generation of the flow [I], or with the usage of the flow [I].
- [B] represents the benefits or profits associated with the usage of the resources [C].

I am uncertain about the role of timing, but I outline the cause of that uncertainty here, to keep it in mind.

- When the input [I] pre-exists the costs [C] then we have the situation used to describe a power drill, and efficiency refers to the usage of [I] to achieve things (e.g. drill holes). Here the benefits [B] and the costs [C] are simultaneous, even as [I] is transformed to [B] and [C].

Figure 01 – ICB Pictogram



- But, when the costs [C] pre-exist the income [I] then there may be an unpredictable delay between experiencing the costs and reaping the benefits. If costs are paid off first, then the timing is investment [C], then as income [I] comes in you recoup the costs [C] and, if lucky, also reap the benefits [B].

The difference in the two scenarios arises from the different effect on the pre-existing pool of resources. In one, the amount of useful resource is augmented, and in the other the amount of useful resource is reduced. I think I will have to defer an exploration of this difference to the NTF in which I explore the nature of chains of transformations, at which time I can look as the sources of that "pre-existing" resource. In some cases the pre-existing resource may be very small (e.g. in an embryo) and large positive returns are needed to pay for growth. In other cases (e.g. fossil fuel deposits) the pre-existing resource may be large and non-renewable (in historic time frames) and so the resource is depleted causing de-growth. The perspective is then dependent upon the definition of the system being considered, and the boundary defined for that system.

For the remainder of this entry I do not use the square brackets for I, C and B.

3.2 - Definitions η, 𝓡 and 𝓝

I want to here define more completely the three different measures of efficiency described in the background section:

- $\eta \equiv B / I$ – which I will refer to as "Odum's Efficiency" since he used that definition in his Ref B article. The usual context in which this is used in when a pre-existing pool (or store or flow) of energy is converted or transformed into some other form of energy, and, in the process of transformation, some of the energy is converted to waste heat. When the transformation happens under someone's control, there is usually a purpose. That portion that does not serve the purpose is the cost of transformation, and that portion that does serve the purpose is the benefit. This is the language of engineers when designing a power dam, a power drill, or some other machine or mechanism, and the goal is to reduce the wastage and increase the portion that serves the purpose. In this language, the total amount of useful energy is always reduced, as some is unavoidably wasted.
- $\mathcal{R} \equiv I / C$ – which is the gross amount of resource (harvested, or incoming) divided by the amount invested or spent to achieve it. In Dr Hall's Ph.D. these this was called EROI, which stands for energy returned over energy invested (sometimes called EROEI). It resembles the concept of return on investment (ROI) found in financial writings. However, I will denote it herein as $\mathcal{R}$ because (a) I eventually want to extend the meaning to apply to chains of energy transformations (e.g.), and don't want to abuse the original name when I do so, and (b) I want a single-letter symbol to use in formulae. Usually the expenditure or investment of energy or money happens before the returns can be garnered or harvested. It is easy to see how this is applicable to activities such as farming, fossil fuel extraction, hunting and gathering, or business investment. This is the language of biophysical economics, and the language of commerce. In this language, the total amount of useful energy is increased, hopefully, after some is spent.
- $\mathcal{N} \equiv B / C$ – which is the net amount of resource (harvested, or incoming) over the amount invested or spent to achieve it. In Wikipedia this is called NEG, standing for net energy gained. This is very similar to $\mathcal{R}$ in construction and use. Again, I will denote it as $\mathcal{N}$ for the

same reasons as given above. This language is often used in discussions of energetics, but a similar concept is often seen in commerce when discussing profitability. It is in general a more volatile measure of efficiency, since any change in one variable (B or C) involves a direct change in the other. E.g. if costs rise, profits fall, and the ratio changes dramatically. This volatility makes it a more sensitive measure of efficiency than the other two, but also makes it more difficult to interpret.

I note that, the goal of engineers and managers is to increase the measure of efficiency. However there is some confusion around the common formulae and usage. For example, the Ref D Wikipedia article defines the "efficiency ratio" as the reciprocal of $\mathcal{R}$ and then goes on to provide an example using $\mathcal{N}$. What's with that? That article argues, correctly, to say that managers need to reduce the ratio $1/\mathcal{R}$, but does not clarify that it is apparently talking about two different ratios.

Table 01 – Definitions.

Definitions of Flows		
I = Income or Gross Returns	C = Costs or Investments	B = Benefits, Profits, or Net Returns
Definitions of Efficiency Formulae		
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3.3 - Conversions

My goal in this section is to complete a 3 x 3 matrix of formulae in which I represent each of the three ratios in terms of the other two. In other words, I want to fill in the missing six formulae in the following table.

Table 02 – Proposed table of conversions of efficiency formulae.

	η	$\mathcal{R}$	$\mathcal{N}$
η	$\boldsymbol{\eta = \eta}$	$\boldsymbol{\eta} = ?$	$\boldsymbol{\eta} = ?$
$\mathcal{R}$	$\boldsymbol{R} = ?$	$\boldsymbol{R = R}$	$\boldsymbol{R} = ?$
$\mathcal{N}$	$\boldsymbol{N} = ?$	$\boldsymbol{N} = ?$	$\boldsymbol{N = N}$

Table 03 – Temporary identification of cell numbers in table.

	η	$\mathcal{R}$	$\mathcal{N}$
η	**1**	**2**	**3**
$\mathcal{R}$	**4**	**5**	**6**
$\mathcal{N}$	**7**	**8**	**9**

The mathematics is purely manipulations of the three defining formulae. The formulae for cells 1, 5 and 9 are already there.

TABLE 04 – Derivations of Conversion Formulae.	
Cell #2 – Expressing η in terms of ℛ.	
$$\eta \equiv \frac{B}{I} = \frac{B/C}{I/C} = \frac{(I-C)/C}{R} = \frac{(I/C)-1}{R} = \frac{R-1}{R}$$	Equ 01
Cell #3 – Expressing η in terms of 𝒩.	
$$\eta \equiv \frac{B}{I} = \frac{B}{(B+C)} = \frac{B/C}{(B+C)/C} = \frac{N}{(B/C)+1} = \frac{N}{N+1}$$	Equ 02
Cell #4 – Expressing ℛ in terms of η.	
$$R \equiv \frac{I}{C} = \frac{1}{C/I} = \frac{1}{(I-B)/I} = \frac{1}{1-(B/I)} = \frac{1}{1-\eta}$$	Equ 03
Cell #6 – Expressing ℛ in terms of 𝒩.	
$$R \equiv \frac{I}{C} = \frac{B+C}{C} = \frac{B}{C}+1 = N+1$$	Equ 04
Cell #7 – Expressing 𝒩 in terms of η.	
$$N \equiv \frac{B}{C} = \frac{B/I}{C/I} = \frac{\eta}{(I-B)/I} = \frac{\eta}{1-(B/I)} = \frac{\eta}{1-\eta}$$	Equ 05
Cell #8 – Expressing 𝒩 in terms of ℛ.	
$$N \equiv \frac{B}{C} = \frac{I-C}{C} = \frac{I}{C}-1 = R-1$$	Equ 06

Table 05 – Table of conversions of efficiency formulae.

	η	**ℛ**	**𝒩**
η	$\boldsymbol{\eta = \eta}$	$\boldsymbol{\eta = \frac{R-1}{R}}$	$\boldsymbol{\eta = \frac{N}{N+1}}$
ℛ	$\boldsymbol{R = \frac{1}{1-\eta}}$	$\boldsymbol{R = R}$	$\boldsymbol{R = N+1}$
𝒩	$\boldsymbol{N = \frac{\eta}{1-\eta}}$	$\boldsymbol{N = R-1}$	$\boldsymbol{N = N}$

3.4 - Relative Ranges

The relationship between $\mathcal{R}$ and $\mathcal{N}$ seems pretty straight-forward, but their relationship with η is curious. We all know that efficiency η is usually defined on the interval [0, 1], and negative efficiency is never mentioned. When thinking of a power drill, for example, the efficiency can range from zero to some highest possible value in the interval [0, 1), never achieving the value 1. So it is natural to retain that perspective.

The definition of η that I give in section 3.2 above uses the symbols and concepts embodied in the equation I = B + C, as discussed in section 3.1. Those symbols, in turn, were derived in the Ref A diary note. In that note I was interested primarily in “Power vs Efficiency” curves for persistent activities. All activities in that exercise showed a profit, and those parts of the curves that did not show a profit were hidden. So, I am guilty, in that instance, of ignoring negative efficiencies. At the time I considered them “out of bounds” values, to be discarded. But, now, I see they have some meaning.

To be clear, income (I) is always in the interval [0, ∞). But, in economics it is often the case that investments (C) exceed returns (I) and the business suffers a loss – i.e. a negative profit, or a negative benefit. In that case, B is negative. So η can be negative, in that instance. And, furthermore, in biology, a hunter can fail to capture large enough prey, or any prey, and suffer a loss of energy. Again η can be negative.

So, to explore that issue, I want to look at three graphs:

- What happens to $\mathcal{R}$ and $\mathcal{N}$ when η is in [0, 1]?
- What happens to η when $\mathcal{R}$ is in [0, 2] (i.e. when I is close to 0?
- How do I interpret those parts of the graphs produced in the Ref A NTF that are negative?

In the Ref E spreadsheet I have produced some useful graphs.

3.4.1 - $\mathcal{R}$ vs η, for η∈[0, 1]

Figure 02 – Graph of $\mathcal{R}$ and $\mathcal{N}$ vs η.

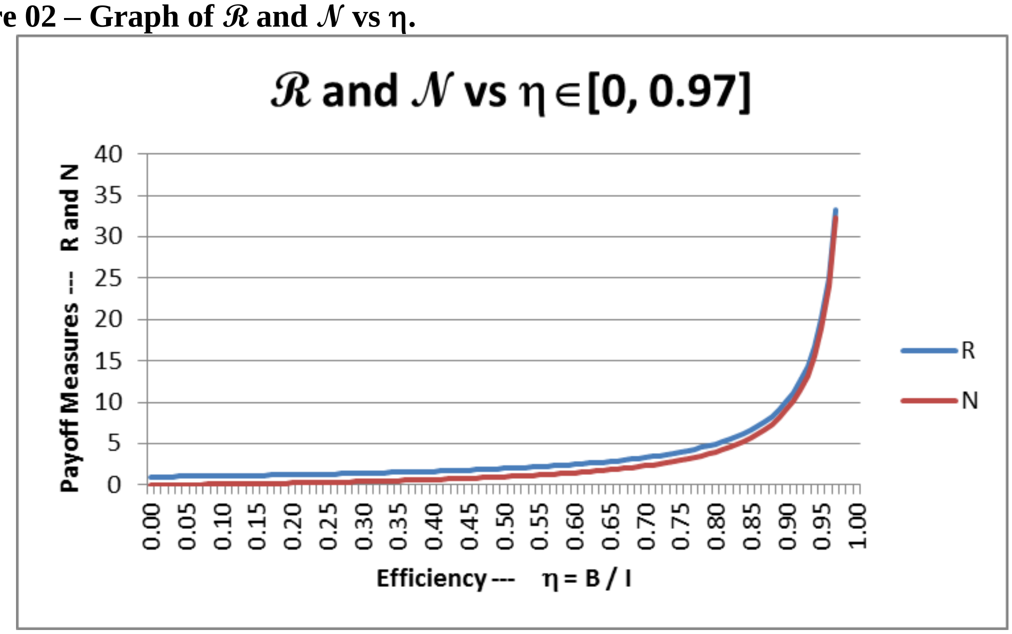
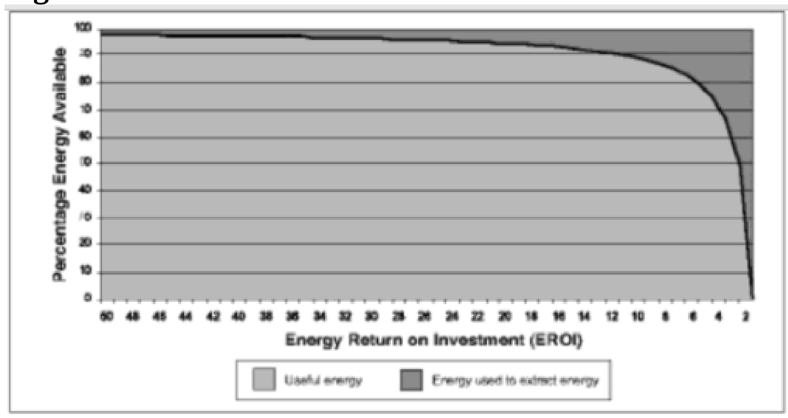


Figure 03 – Classic EROI Knee Curve.



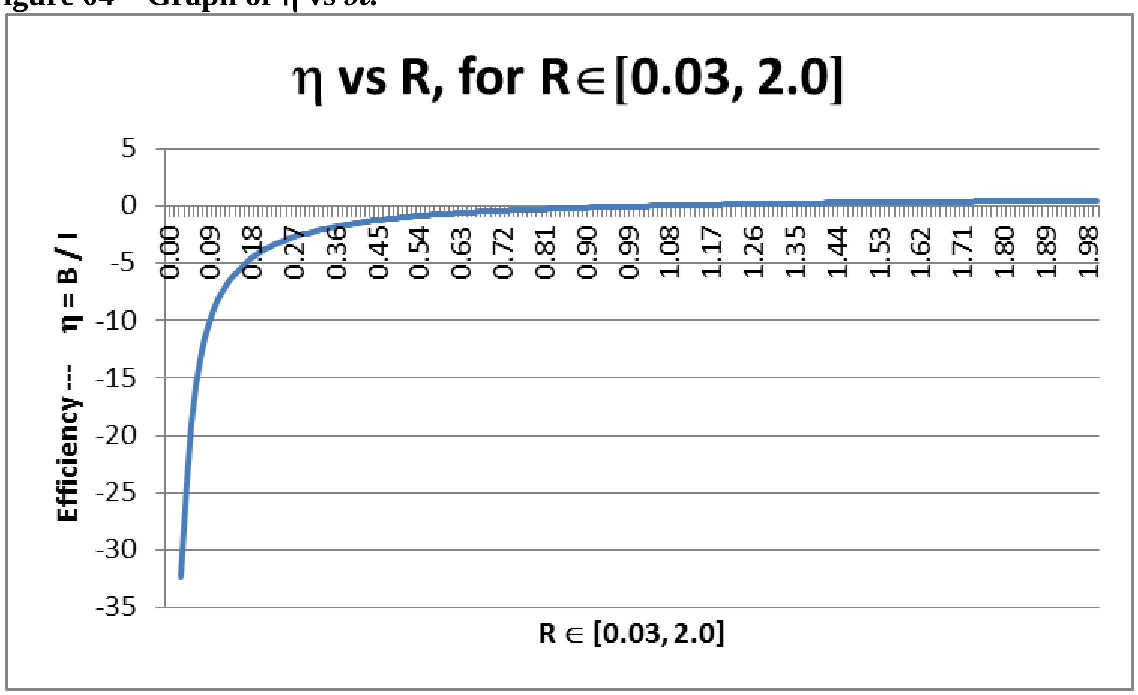
In Figure 02 I stopped plotting at $\eta = 0.97$ because above that $\mathcal{R}$ shoots up towards infinity, and the graph just looks like a tipped over capital L. With this scaling we see the familiar knee curve from biophysical economics presentations (see figure 03).

Back to Figure 02 again, $\mathcal{R}$ starts at 1 when $\eta = 0$ and rises from there towards infinity when $\eta = 1$. It becomes apparent that in this knee curve presentation the conditions for energetic or commercial loss (i.e. $\mathcal{R}<1$) are not shown.

3.4.2 - η vs R, for R∈[0.03, 2.0]

So, to see what is happening in that region of the domain of $\mathcal{R}$ for which the entity is operating at a loss I switched the roles of the two axes, and looked at the variation in η as $\mathcal{R}$ went from 0 to 2 (see Figure 04). In this graph I note that, when $\mathcal{R} = 1$, then $\eta = 0$, and η rises towards 1 as $\mathcal{R}$ rises towards 2. This is consistent with Figure 02, for those ranges of $\mathcal{R}$ and η. The interesting part happens for $\mathcal{R}\in[0, 1]$.

Figure 04 – Graph of η vs $\mathcal{R}$.



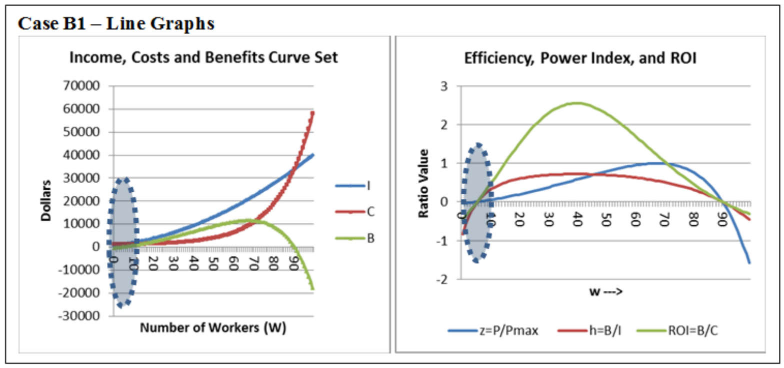
The graph in Figure 04 starts at 0.03, again, to avoid an attempt to plot negative infinity. Once again I note the shape of the EROI knee curve, but with a different orientation. Here we now see negative efficiencies. I am reminded of the merchants of Venice who, in the 1600s, referred to negative financial accounts (debts) as “numeri ficti”, or fictitious numbers, fictitious money. They knew that debts were real, but they could not imagine what negative money would look like. Similarly, I cannot imagine what negative efficiency means, other than the apparent association with investments for which the returns are inadequate to cover the investment.

3.4.3 - η, ℛ and ICB Curve Sets

At Ref A I completed what I believe to be an exhaustive review of every possible way a single “factor of production” could interact with business accounts I, C and B for a prosperous business for some reasonably short but sufficiently long duration of time. I.e. the duration of time is long enough to ensure that the returns directly derived from an investment can be accounted, but not longer. The analysis there does not intend to look at (a) a series of ongoing investments, such as would characterize most successful business, or (b) investments that incur losses, or (c) the effects of multiple factors of production. I intend to address point (a) in the Ref G diary entry. I intend to address point (b) here, now. Point (c) will need to remain in abeyance for the nonce.

Figure 05 – Case B1 – First Graphic – Page 36

I have arbitrarily decided to use a parabola and an exponential curve to demonstrate this characteristic.



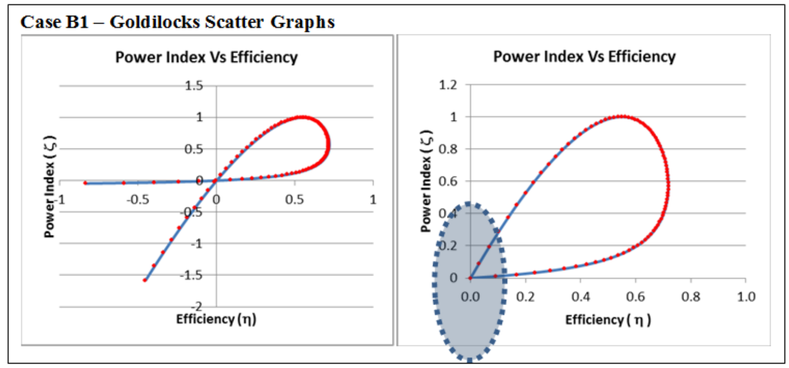
The curve set is an element of **Π**.
The focus is on $w=w_L=5$. $I(w_L)=C(w_L)>0$. $B(w_L) = 0$. w_L, i.e. the lower bound of the interval on which $B(w)$ is positive, is located at $w=5$.

I am going to use the graphics from Case B1 (page 37) of the Ref A diary note to rethink the issues around negative efficiencies. In Figure 05 there are two graphs:

- In the Graph at the left of Figure 05, I have arbitrarily posited an exponential rise in costs associated with a quadratic rise in returns, resulting in a diminishing return for a large workforce. There is a staffing level below which no profit is possible, and a staffing level above which no profit is possible, and a Goldilocks region for which profits rise from zero to a maximum, and then fall again. A profitable business having such an operating space would undertake some investment, and experience costs, income and profits according to the current manning level. That the posited meaning of this graph.
- In the Graph at the right of Figure 05, I have constructed three measures of effectiveness and efficiency:
    - η = B / I;
    - ROI = B / C which in this note translates to 𝒩 or ℛ-1; and
    - a power index, which is benefits per unit time divided by the maximum power possible for this ICB curve set. For example, the benefits are maximized at a manning level of about 70 workers, where the power will be greatest, but a firm with 40 workers will have a lower power, and the index will be power (at 40 workers) / power (at 70 workers).

In Figure 06 I copy the graphics from Ref A, top of page 37, in which I look at the iconic Goldilocks curve generated as a scatter plot using the data displayed in the Figure 05 curve sets. When I wrote that entry, 16 months ago, I discarded the negative efficiencies as meaningless, largely because (a) my focus was on profitable business circumstances, and (b) I did not understand that fictitious efficiencies with negative values had any meaning. I am now in a better position to interpret the negative efficiencies. Looking at the graph on the left in Figure 06:

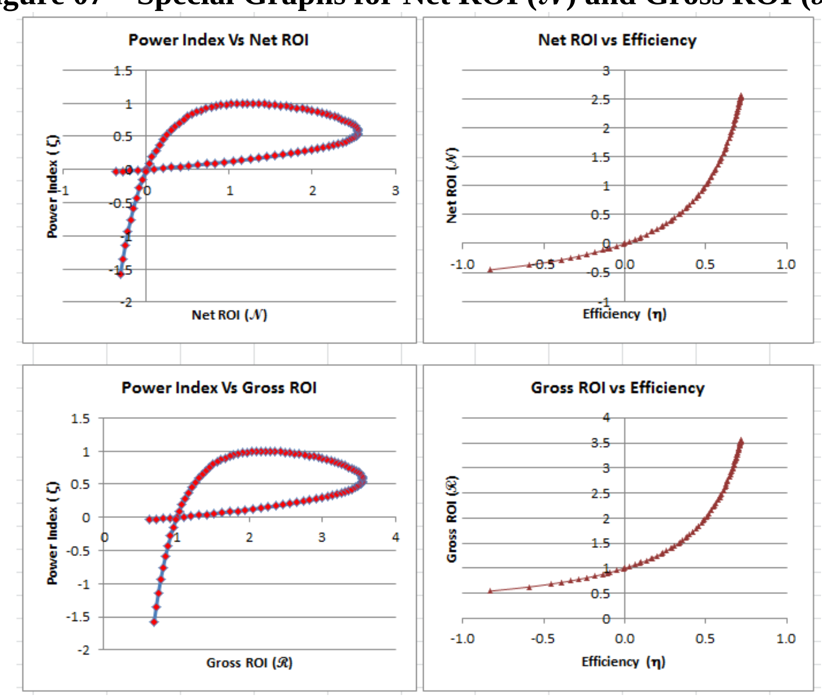
Figure 06 – Case B1 – Second Graphic – Page 37



Some of the data points are meaningless, falling elsewhere than in the 1st quadrant. The meaningful points are graphed to the right. The shaded oval indicates the area of interest in the graphs.
Focus on w = 0. $\zeta(w_L) = 0$. $\eta(w_L) = 0$.

- The upper branch of the negative efficiencies has a mild negative power index. There are four red dots representing the (ξ, η) coordinates for the staffing levels of w = 1, 2, 3 and 4.
- At w = 5 the power index (ξ) is zero and the efficiency (η) is zero.
- When it moves into positive efficiencies, increased manning slowly raises the power index and the efficiency.
- Eventually, as staffing rises, the efficiency is at maximum.
- Further increases to staffing cause reductions in efficiency, but, for a while, the power index continues to rise.
- Eventually, as staffing increases, the business is at maximum power.
- Futher increases to staffing then cause reductions to both power and efficiency.
- At some point additional staff bring the business to a break even point for which both the power index and the efficiency are zero.
- Additional staff then cause a steep decline into high rates of loss. The steep drop is, of course, due to the fact that I arbitrarily decided to model costs using an exponential

Figure 07 – Special Graphs for Net ROI (𝒩) and Gross ROI (ℛ).



function, so the slope of the curve is of little interest. I think what is important to note is the fact that inadequate staffing levels position a business on the lower branch of the Goldilocks loop, and excessive staffing levels position a business on the upper branch.

In Ref A my focus was on net return on investiment ($\mathcal{N}$), but EROI ($\mathcal{R}$) is a version of gross return on investment, so I have redone the last graphs of Ref A, case B1, rather than copying them, and I have added similar graphs for $\mathcal{R}$. I note that we get a Goldilocks loop for the power index vs efficiency for all three definitions of efficiency. And the role of $\mathcal{R} > 1$ as a criterion for profitable activity is clear in all cases involving $\mathcal{R}$.

3.4.4 - Galbraith's Theory of the Firm

When I was studying for CATM and CMC certification there was a curious issue that came up several times which was essentially swept under the rug. Efficient corporations cannot be sustainable. High Tech companies are the worst, but the same argument applies to all composite companies – i.e. those having vertical integration, conglomerate organization, or multi-national footprints. High Tech companies, for example, do not try to be efficient, except for when it comes to manufacturing. They are profligate spenders when it comes to R&D, A&M, advertising, and infrastructure replacement and renewal. While one worldwide network is still only partially deployed they make it obsolete by replacing parts with newer technology.

My line of thought has two parallel lines of reasoning, and they go like this:

- Suppose a company has ten products that are all selling relatively well, and ten internal "project centres" that manage those ten products.. The shareholders want to maximize their quarterly profits, or they sell the shares and buy the shares of other companies, driving the price of these shares down. So, to maximize the return to the shareholders, they would rank the performance of all ten project centres, prioritize them, and sell of those that are under-performing. If they keep only the top performers, then they improve the ROI on the stocks, the shareholders are happier, the stock price goes up, the company has more access to debt, and the business does well. But this is an ongoing process, and eventually, all persistent corporations would have only one or two market-dominating products. This argument, taken to its ultimate extreme, would preclude the existence of conglomerates, or the activities around mergers and acquisitions (M&A).
- Or, suppose a company retains some of its earnings, diverting them from the quarterly dividend that investors expect, and spends them on frivolous things like R&D or corporate brand advertising. Again, the shareholders dividends take a quarterly hit, they sell the shares, and the corporations loses access to debt financing. So, corporations must then ensure that all such costs not directly associated with the manufacture of marketable products are reduced, maximizing the flow of earnings into the pockets of the shareholders. If you take this argument to its ultimate extreme, all corporations must be highly focused on reduced efficiency.

Certainly, most large corporations are experts at reducing costs associated with both the manufacturing facilities, and the products produced there. But a large part of the price of those products is administrative overhead. This includes R&D, A&M, debt financing, management salaries, corporate branding, multiple corporate office compounds, etc. These costs are charged to the customers, and not passed on to the shareholders.

If you take both of these lines of thought to their obvious conclusion, the modern multi-national or high-tech corporation should not succeed. I.e. it does not maximize efficiency – it does not maximize ROI – and yet it dominates the modern economic landscape. The business model is not based on returning maximum value to the shareholders (the owners), but something else. In 1968 John Kenneth Galbraith argued (see Refs H and I) that modern firms have broken away from the grip of the owners, and are managed by a self-serving info-structure, a cadre of specialists, who give the owners the minimum necessary to keep them happy, and retain the rest of the earnings to pay for (a) persistence, in the form of risk avoidance; and (b) growth, in a variety of forms including multiple product lines, multiple markets, vertical or horizontal integrations, multi-national footprints, and disengagement from the unpredictability of the biophysical economy.

I find an explanation for this phenomenon in Odum's MPP, and in my Goldilocks curves. The Ref A diary entry is one-dimensional. It only examines the effect of a single factor of production. But the concept can be generalized to all relevant factors of production. The associated graph would be power as the dependent variable, plotted against the efficiency of the consumption of all input factors, producing a kind of a bubble. Maximum returns would be associated with the extremum of the resulting multi-dimensional bubble (replacing the loop). Nevertheless, without loss of generality, I believe I can still focus on the one-dimensional example. In my Ref A example I let staffing level vary from 0 to infinity, and find that for some minimal staffing level break-even is possible, and for some maximum level and beyond, returns are negative again.

Looking at the Goldilocks loops in Figures 06 and 07, we see that there is a staffing level (a level of consumption of this factor of production) for which efficiency of its use is maximized, but the power of the benefits is not yet maximized. I want to focus on that range of consumption between maximum efficiency and maximum power.

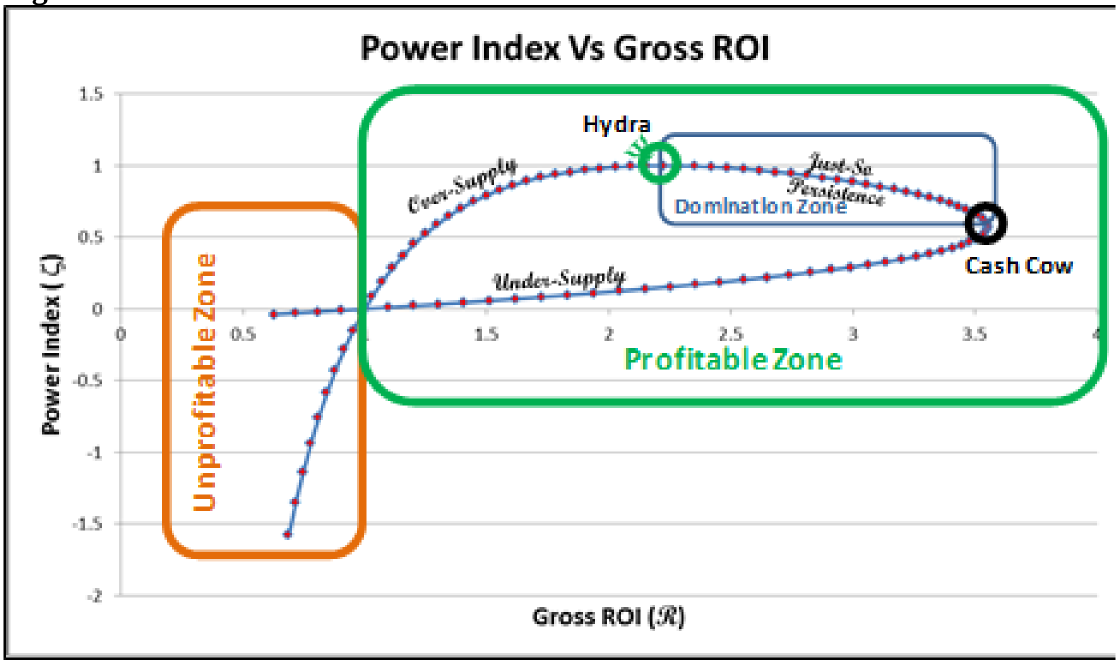
- Point of maximum efficiency (η) – I believe/I think/I hypothesize that, if perfect competition (see Ref J) were to actually exist in the marketplace, this level of consumption (e.g. of staffing) would characterize factors of production in all corporations. This would define the attractive point in the state space. This would define the equilibrium of general equilibrium models. I suppose that "cash cow" corporations in over-mature and declining market segments would find themselves at this point on the multi-dimensional power vs efficiency curves. I also suppose that organisms such as sloths, lichen, angler fish would be characterized by such maximized efficiencies. They extract every ounce of profit possible out of every input. Time is not an issue for them. I note that ***ℛ, 𝒩*** and η all peak at the same staffing level, so it doesn't matter which kind of efficiency we are talking about.
- Point of maximum power index (ξ) – At a substantially higher staffing level (higher consumption rate of the factor of production) the efficiency is less, but the rate of generation of returns is increased. That is, the returns per unit of consumption is reduced, but the returns per unit of time are increased. Moreover, a significant part of those increased returns must necessarily be retained to pay for the increased staffing level. Such points of maximum power would be where most high-tech or multi-national or conglomerate corporations would be located. I would suppose that apex predators such as lions might not be efficient eaters, leaving behind the skin, bones and entrails of their kills. I also suppose that mankind tends to

operate at maximized power.

- Then there is the range of levels of consumption between. I could imagine organisms or organizations functioning anywhere along the curve between these two extrema.

Now, there's an interesting thought. Suppose that the metabolic systems within a single organism are not polarized between efficiency of metabolic activities, and effectiveness of growth and reproduction. Suppose they are all arranged somewhere along the curve, with reproduction falling near the top somewhere. Then, the metabolic systems within an organism would be analogous to the corporations within an economy.

Figure 08 – A Dissection of the Goldilocks Curve



In Figure 08 I have taken a copy of the Goldilocks curve for gross ROI and dissected it into five segments. The two on the left (one is an extension of the over-supply branch, and the other of the under-supply branch) are in the unprofitable zone. The other three are in the profitable zone. The highly efficient "cash cow" corporation (the black and white icon) would be located at the far right, marking the line between under-supply and "just so". The super-aggressive type of corporation that I call the "multi-headed hydra" – the type described by Galbraith – is represented by the green multi-headed icon.

The entire "profitable zone" is actually a multi-dimensional continuum, and I suppose any firm located in this zone is on its way from or to success. This is NOT a dynamic diagram. It is a snapshot in time. But, even so, I think that (I hypothesize that) most healthy businesses are in the "Just So" segment, and that (hyper-spatial) segment would define the stationary state to which our modern economy has evolved.

In past times, empires and nation states occupied the "multi-headed hydra" position. Now-a-days, it is also occupied by multi-national corporations.

However, I would also hypothesize that the global economy, as a whole, is a multi-headed hydra that has moved into the unprofitable zone, and is no longer sustainable. We are extracting more energy from the Earth than is going into the Earth, and the overall EROI is below 1. It is not sustainable.

3.5 - Reconciliation of Two Paradigms

It seems that simply knowing the conversion formulae for η, $\mathcal{R}$ and $\mathcal{N}$ does not remove all confusion. In particular, η and $\mathcal{R}$ seem to embody two different intuitive paradigms that appear to be the same (i.e. efficiency as η vs efficiency as $\mathcal{R}$) whereas they are different.

3.5.1 - A Difference of Paradigms

Consider a store of resource (I_0) that is under the control of some organism or organization. We have two paradigms – a decay paradigm, and a growth paradigm. Why do I confuse them as being the same? Because they have the same intuitive form, and formula:

- In a situation in which depreciation, decay, or consumption of a fixed resource is being modeled, we use the concept $\eta = I_{n+1}/I_n$ where $I_{n+1} < I_n$, and $0 \leq \eta \leq 1$.
- In a situation in which growth or accretion of assets or scope of control is being modeled, we use the concept $R = I_{n+1}/I_n$ where $I_{n+1} > I_n$, and $1 \leq R$.

They look the same! But when I look at the iterated application of each concept, they diverge in application.

Table 06 – Comparative Micro-Steps in Iterative Application of η and $\mathcal{R}$.			
Decay Paradigm		**Growth Paradigm**	
I_0	Initialization	I_0	Initialization
$B_0 = \eta_0 I_0$ $C_0 = I_0 – B_0$	Application	$C_1 = I_0$	Bridge
$I_1 = B_0$	Bridge	$I_1 = R_1 C_1$ $B_1 = I_1 – C_1$	Application
$B_1 = \eta_1 I_1$ $C_1 = I_1 – B_1$	Application	$C_2 = I_2$	Bridge
$I_2 = B_1$	Bridge	$I_2 = R_2 C_2$ $B_2 = I_2 – C_2$	Application
$B_2 = \eta_2 I_2$ $C_2 = I_2 – B_2$	Application	$C_3 = I_2$	Bridge

Here η_0, η_1 and η_2 are a series of value of η, and $\mathcal{R}_1$, $\mathcal{R}_2$ and $\mathcal{R}_3$ are a series of values of $\mathcal{R}$. They are related by the formulae $\eta_n = (R_n - 1)/R_n$ or $R_n = 1/(1 - \eta_n)$. These conversion formulae seem to fly in the face of the intuitive notion that both are based on the concept of the ratio of I_{n+1}/I_n.

The differences in the two algorithms are:

- η_0 is defined but $\mathcal{R}_0$ is not.
- The role of I_n seems to be the same (total resource under control), but the roles of C_n and B_n

are a little different. This is particularly clear in the step that bridges from one iteration to the next.

I think the difference arises from the implied normative interpretation of the words "benefit" and "cost". In the decay paradigm, a change in I_n is always negative, and is to be avoided, and so gets the pejorative assignment of the concept of "cost". But, in the growth paradigm, a change in I_n is always positive, and is to be sought out, and so gets the implicit approval of the concepts of "benefits", profits, or returns assigned to it.

3.5.2 - Implications of Two Paradigms

The realization, at this point in my studies, that these two paradigms entail two different interpretations of quantities (expenses and profits) putting them in opposite roles raises some difficult questions:

- Do I need to revise most of my notes written since December 2015, i.e. since I wrote the Ref A NTF? It makes me wonder if I haven't made some BIG error in the past, requiring me to do some substantial revision of much of my notes. I would trace the threads of these two paradigms back to the Ref A diary entry in which I investigated the absolute ubiquity of Goldilocks curves. That is a REALLY KEY concept coming out of the study of Odum's MPP.
- Is one paradigm better than the other? The η-based paradigm has its roots in the work of Carnot, and is almost universally used by all engineers of energy-consuming systems and equipment. The $\mathcal{R}$-based paradigm has its roots in economic theory, as adapted by Dr Hall for use in ecology, and is now almost universally used by ecologists and by analysts of energy-extraction industries.
- Is there some easy way to reconcile or merge these two important and widely-used paradigms?

The first question gave me reason to pause and worry, but, after some thought, I believe those concerns have no foundation. I do recall that originally I had serious difficulty coming up with the ICB schema as summarized in Table 01 above. But, once having achieved that summary, I was able to produce spreadsheet models in which I could model I_n, C_n, B_n, η_n, $\mathcal{R}_n$, and ξ_n (i.e. power index) all at the same time. The two paradigms are like a Venn diagram for which some internals are different, but many aspects are the same. The stop-time snapshot of the values at time t_n are consistent within both paradigms, and the formulae for conversion are the same for both paradigms, even if the steps taken to advance t_n to t_{n+1} are different. The good news is, the ICB study at Ref A was entirely based on the η-based decay paradigm, and did not mix them, and all graphs are representative of the formulae common to both paradigms.

The second question provokes some interesting thoughts. The η-based decay paradigm disallows negative values of efficiency, and so eliminates consideration of those situations that are implicitly growth producing. At the same time, the $\mathcal{R}$-based growth paradigm disallows values of $\mathcal{R}$ less than one, and so eliminates consideration of those situations that are implicitly decay producing. Each is suitable for the purposes for which it was developed, but each has an implicit blind spot. I am inclined to think it is easier for most people to imagine extending the domain of $\mathcal{R}$ from $[1, {}^{+}\infty)$ to $[0, {}^{+}\infty)$ than it is to change the domain of η from $[0,1]$ to $(-\infty, 1]$. Somehow the concept of negative efficiency is difficult to grasp. So, in my opinion, the growth paradigm would be more easily extended to cover decay. But I suspect either could be effectively extended to do the job of the other.

But, further to that, one can think of growth and decay in many contexts. Does the consumption of a non-renewable resource fall into the growth or decay regime? What if that non-renewable resource is available in immense quantities, free for those who have the opportunity to dig it up, as is the case with coal and oil. Is it growth at first, and decay later? I think so. There are then two possible causes of growth or decay: intrinsic constraints, and extrinsic constraints. A paradigm then needs to be flexible enough to address such variety of dynamics.

To address the final question, I will terminate this NTF and start a new one.

4 - Summary

Table 04 meets the purpose of this diary note.

5 - Yet-To-Do

I do need to think about the merger of the two paradigms. I will address that in a separate diary note. Refs K, L and M are three parts of one investigation. Ref K (this NTF) is the first, and can be considered Part I. Ref L is Part II, and in that NTF I try to merge the two paradigms, while examining the effects of recursion such as in irregular feeding. Ref M is Part III, and in that NTF I examine the effects of recursion such as in trophic chains.