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Using Portfolio Theory to Improve Resource Efficiency of Invested Capital

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Abstract

Limited literature provides concrete, theory-based methods for quantifying the effects of sharing capital. This paper describes the potential contribution of portfolio theory to quantify the effects and optimize the employment of capital (human, tangible, financial, and service employing capital) in a theoretical and quantitative manner in the context of sustainability. Insights illustrate how portfolio principles can yield benefits, including the fulfillment of needs using fewer resources, consistent with sustainability. In particular, "pooling" assets to meet uncertain demands from different users of an asset pool may yield benefit from diversification effects. Suggests future research avenues such as the management of high-value, critical-value, and expiring resources to support sustainability.

Key Words

Resource use; need fulfillment; quantification; Product/Service System; servicizing; value creation; risk reduction, asset pooling.

1. Introduction

The diligent use of capital of *all forms* contributes to sustainability.[1] The basic capital forms are human, tangible, and financial, with additional categories, e.g., human physical and mind capital. The use, organization, and management of forms of capital can support need fulfillment. “Service” sometimes is one aspect of need fulfillment. A reduction in capital used to fulfill human needs, other things equal, represents an increase in capital efficiency – in support of sustainability. “Sharing” a pool of capital (human, tangible, financial, “service”) can reduce capital employed and add to capital efficiency. To illustrate the use of physical product (a form of capital), consider car sharing by companies such as Zipcar. Such a change in practice reflects a phenomenon sometimes called servicizing (White et al., 1999). The potential positive contribution of servicizing to environmental sustainability has nurtured debate the last two decades with such concepts as Service Economy (Stahel, 1994) and Material Input per Service Unit (MIPS) (Weizäcker et al., 1998).

Few studies address the quantitative effects of the efficient use of physical products on sustainability. Virtually no literature provides a theoretical formulation of quantification of the effects of efficient resource use. Tukker (2004) brought light on the topic, arguing in a semi-quantitative manner of the possibility of reducing environmental impact by up to a factor of 2 through a type of asset pool. Tucker offers no theoretical foundation for the quantification. The absence of attention to asset pooling contrasts with the development of industrial methods and practices of quantifying the environmental impact of the use of a single physical product, e.g. by using Life Cycle Assessment (LCA) (ISO, 1997). However, attention to efficient asset employment at a system level is critical and offers the promise of leveraging of effect. Larger improvements often stem from system level rather than single product application (see “system innovation” (Brezet, 1998)).

To fill this gap, this paper provides theory and insights on the quantification of effects of the efficient use of capital at a system level *that stem from application of portfolio theory (PFT) to non-financial assets.* The PFT model is quantitative and enjoys numerous applications in finance. The originator of PFT and subsequent derivative developments have garnered Nobel Prizes in economics. Practices tied to the prescriptions of PFT but applied to non-financial forms of capital offer the promise of contributing to environmental sustainability. The core perspective: a pooled asset, portfolio approach to asset management will yield a reduction in assets employed and recovered, or “used up” to provide need fulfillment.[2] Reducing capital employed and/or used up increases the efficiency of capital employed and contributes to sustainability.

This paper draws on the intuitive and logical outcomes of PFT to develop practices that support environmental sustainability. This paper describes potential contributions of portfolio theory in a theoretical and quantitative manner to asset use to meet requirements, and hence environmental sustainability. The approach draws on the application of a well-established theory to non-financial areas. The development and discussion spawns new possibilities for further research and practices.

Section 2 provides a brief literature review from the “finance side” of literature, limited to seminal papers that support the background section. The scant review for “sustainability and servicizing side reflects the paucity of literature related to the thrust of the paper. The literature gap identified in Section 2 prompts Section 3 that targets the application of PFT in this area. To move toward quantification at a system level, Section 4 offers an overview of the core issues and implications of PFT. Section 5 develops ideas to support application of PFT. Section 6 relates principles of PFT to invested capital and provides avenues of research. A summary and conclusions reside in Section 7.

2. The Literature

2.1. Finance

Modern portfolio theory originates with the seminal work of (Markowitz, 1952). Markowitz developed the formulation of an efficient frontier from which an investor could choose their portfolio to maximize return for a given level of risk as measured by the variance of returns. A key insight from this work was that assets could not be selected based solely on their unique characteristics of return and variance. Rather, an investor had to consider the correlation of the returns of an asset with the returns of all other assets. Taking into account these co-movements allowed the construction of a portfolio that had the *same return with lower risk* than a portfolio that ignored the interactions (Elton and Gruber, 1997).

Sharpe (1964) and others ((Lintner, 1965) and (Mossin, 1966)) recognized and advanced the potential implications of portfolio theory. Building on the work of Markowitz, Sharpe developed the capital asset pricing model (CAPM). The CAPM quantifies an investor's required expected rate of return on an asset given the asset's sensitivity to systematic (market) risk. Other researchers tested the CAPM and developed various versions of the model over the years, most notably Fama and French (1992). Many more researchers developed and offered important variations, tests, and applications of the basic models. All these efforts rest on the bedrock of the early explorers, with references in this paper a minute *sampling* of the many significant contributions.

The results of the PFT research have affected the management of money and other assets worldwide. The genius of these ideas and the intellectual leverage brought by many of the greatest minds in finance bridged the gap from mathematics to reality, resulting in trillions of dollars of assets invested and managed according to the prescriptions of PFT. The Nobel Committee recognized these tremendous achievements and contributions conferring both Harry Markowitz and William Sharpe with the 1990 Nobel Prize in Economics.

Motivation for this paper stems from the recognition that the principles of PFT offer the prospect of favorably affecting value creation in areas away from the arena of financial investments. This notion is not unique to our efforts. Others have applied PFT in areas such as cash management, e.g., with a pool of cash meeting uncertain cash needs from those parties that have claims against the pool. However, this paper differs from previous important contributions in that it focuses on specific benefits of portfolio concepts that:

- Are beneficial to the use of capital in need fulfillment, with favorable effects on environmental sustainability.
- Offer the promise of garnering incremental as well as separate potential benefits from servicizing.
- Yield benefits when applied to other activities related to the inputs of production, production itself, delivery, and realization of need fulfillment by people.
- Increase efficiency in the employment of capital, with attendant benefits to organizations, economies, and society consistent with the prescriptions of sustainability.[3]

2.2. Sustainability and Servicizing

We recognize, benefit from, and share a sampling of important contributions of previous researchers. Environmental sustainability has been an important issue in our society in recent decades (Brundtland, 1988). As a means of measuring environmental sustainability, LCA (ISO, 1997), Eco-efficiency (DeSimone and Popoff, 1997) and resource efficiency (Stahel,

1994) have been proposed. These contributions allow measurement of the environmental aspect of a product or a set of products.

To improve environmental efficiency, changing characteristics of a product (e.g., allowing a change in resources used per unit) represents an option. Numerous papers about environmental impact related to product characteristics exist, e.g., (Pfeifer, 1996) and (Azzone and Noci, 1996), and therefore are not a focus in this paper. Another perspective shifts from focus on a physical unit of product to a unit of service derived from use of assets, sometimes called servicizing (White et al., 1999) or Service Economy (Stahel, 1994). Some shifts to servicizing rest on arguments of offering positive contributions to environmental efficiency and realizing dematerialization (see e.g., (Dobers and Wolff, 1999)). Concepts such as Product/Service Systems have enjoyed much debate with the same argument (e.g. (Mont, 2002), (Tukker and Tischner, 2006)). Car sharing is an example of servicizing with group's sharing cars resulting in fewer cars than with individual ownership (e.g., (Williams, 2007)). By taking service as a unit, Material Input per Service Unit (MIPS) (Weizäcker et al., 1998) serves as a useful concept to measure efficiency and to encourage the efficient use of resources.

Servicizing shifts the perspective to the value or utility of need fulfillment derived from a product unit, rather than the unit itself. Focusing on service value use rather than product unit levels (see e.g., "system innovation" (Brezet, 1998)) offers potential gains in efficiency and hence, sustainability. Potential benefits to users exist by fulfilling service needs drawing on a pool of products (assets) accessed by a user, rather than direct ownership. Tukker (2004) asserts the possibility of reducing the environmental impact by a factor of 2, (i.e. reduction by 50%) owing to product pooling. His contribution is one of the few attempts to quantify the effects. However, his calculation rests on a conceptual model. We find no literature providing concrete, theory-based methods for quantifying the effects of servicizing and asset use. Therefore, this paper addresses the effects of product pooling relative to servicizing of need fulfillment of users.

This paper represents one of the first attempts to apply portfolio theory, concepts, and mathematical models to managing as a portfolio of invested capital (in the servicizing context) a pool of physical products or available service units. This approach allows quantification of decisions important in using capital wisely to fulfill needs, thus adding to sustainability.

2.3. Industrial cases

Examples of practices to provide pooled asset capital exist in both B2C (business to consumer) and B2B (business to business). Toyota Material Handling Group (TMHG), based partly in Sweden, is a leading forklift truck producer and offers material handling operations worldwide through a range of products and services. The TMHG rental programs use pooled assets (Lindahl et al., 2009; Sakao et al., 2009). These rental programs offer:

- Rapid response to ensure that the customer's operations keep running;
- Guaranteed performance levels with a money-back commitment;
- Total support from the company's service organization with rapid and guaranteed response times;
- Ability to change or upgrade equipment without additional cost, subject to 3 months' notice;
- Ability to return equipment if it is no longer required without additional cost, subject to 3 months' notice; and
- The option of including a truck driver as part of the rental agreement.

Benefits include flexibility to adjust usage depending on changes in customer needs. Drawing service from a pool can help the customer avoid the uncertainty of forklift truck running costs, and eliminate the need to tie up capital and attendant risks of ownership. The core issue from the point of service realized, asset use, and sustainability: *the total number of forklifts in the pool to fulfill the customers' requirements is less than the number of forklifts needed with individual customer ownership.* How the economic benefits of this are divided up between users and owners of the pool is an important issue, *but not the focus of this paper*. ***That fewer assets result in the same need fulfillment, and potentially with lower costs, is the key issue in terms of sustainability***. Actually, TMHG is not interested in selling the maximum number of forklifts. Rather, TMHG seeks attractive economic returns relative to capital employed – which may result from selling fewer forklifts.

Car sharing is an example from B2C. Potential environmental benefits include reduction of resource consumption attributable to shared usage of vehicles and a decrease of mileage per person. Prettenthaler and Steininger (1999) report that car-sharing rather than individual ownership triggers a reduction of 42% - 50% in miles driven. The short term environmental impact of a car is derives primarily from usage. Longer term, fewer cars in the pool vs. individual ownership affects resource use (to make and support vehicles) and sustainability. In addition, keys for success in car sharing have been identified; e.g., convenience for users who already own one car, and cost advantages for certain non car owners (Johnson et al., 1998).

Published literature addressing the quantification of decreased assets from car sharing is scarce. Honda ICVS (Intelligent Community Vehicle System) discontinued their car-sharing service in Singapore in 2008 after 6 years of operation, stating: "the decision to discontinue the program was reached as it was assessed that it would be difficult to sustain the service with the current operation system."[4] Yamaguchi (1999) offers general information on Honda ICVS. Given the scarcity of literature, theoretical insights in quantitative terms about pooling asset capital will enhance the ability to make informed and informed analysis and support logical decisions in industry.

3. Quantification at a System Level

In the servicizing context, providers' views of products differ considerably from individual purchase choices. The car example illustrate ramifications of servicizing, e.g., redeployment of capital, purchase price of the asset, risk management, asset maintenance, and returns on capital sensitive to asset use versus idle time. Factors related to the diligent use of capital to fulfill needs affect sustainability. Economic profits and value added are sensitive to economic returns *and* the employment of capital over time. Reducing idle time – since idle capital results in negative rather than no returns – not only enhances returns, but increases returns relative to capital employed. Having the same or greater economic and/or social returns with less invested capital is essential to the wise use of resources, and sustainability.

The **Need Fulfillment to Resource Used Ratio** (NFRU). People and other consumers (e.g., cattle at a feedlot) have actual and perceived needs and desires, which for simplicity we collectively term needs. Entities utilize (or contribute to) resources (human, tangible, and financial) to fulfill needs.

$$NFRU = \frac{Need/Desire\ Fulfillment}{Resources\ Employed/Used}$$

Favorably influencing the inputs of production, the production process, delivery, and realization of need fulfillment by people is central to sustainability. Adding to the efficiency in the employment of capital, with attendant benefits to organizations, economies, and society likewise are crucial to the prescriptions for sustainability.

Unemployed or inefficiently employed assets diminish need fulfillment relative to resource use. Hence, enhancing resource use relative to capacity and avoiding idle time favorably alter the NFRU. Need fulfillment is taken into account as a functional unit in LCA (ISO, 1997) and Eco-efficiency (DeSimone and Popoff, 1997). However, usually these approaches target assessment and evaluation of a single asset (e.g., a single product) with a certain function of the asset being the target of assessment and evaluation. Examining a pool of units compared to employing multiple independent single units has not held attention despite the potential reduction in invested assets and idle time that result from asset pooling. Fig. 1 depicts an individual unit vs. pool of assets to fulfill needs. The difference between the two levels is addressed by this article. In A) of Fig. 1, users do not have an exclusive right to the given function, but they enjoy service from the pool of assets and can receive the expected value. In this hypothetical example, in A) six units of resource in the pool supply the needs of nine users, but one unit supplies needs for one user in B). With the single approach, nine users would need nine units. Combining the benefits of the PFT pooling effect with the already matured theory and practice at a single product level (for instance, by LCA) will yield new benefits. This article contributes to quantification at the system or pool level.

<<Position of Fig. 1.>>

Fig. 1. Need fulfillment drawing from pool vs. individual unit use.

Resources encompass financial resources, tangible resources, and human resources. Optimal resource employment *includes* the effective use of human resources. Pooled assets offer the prospects of more efficient use of human resources as well as financial and tangible assets. Wise use of resources favorably influences the employment of human talents with attendant effects on social sustainability. In fact, the effective use of human resources is more important than the use of other resources – *since a human resource is an expiring resource.* At the end of each day, the day is forever gone for a person. In contrast, unused financial or tangible assets have potential future uses, and returns.

The efficient use of resources to fulfill human needs with the resultant earning of economic returns supports employment opportunities. In contrast, the inefficient use of resources has economic costs that fall on society – and rob its members of need fulfillment and the beneficial use of human resources. Such losses are counter to social responsibility and sustainability.

A high need-fulfillment-to-resource ratio implies efficiency in the use of resources. This does not imply a wise use of resources as viewed by individuals or “society.” Wise use (e.g. prolonging product lifetime (Cooper, 2005)) is a separate and important issue sensitive to many issues including cultures, attitudes, and priorities. The authors defer discussion of the details of these issues, e.g., the impact of waste on efficiency, sustainability, costs, etc. to other papers, rather than detract from the focus of this paper.

4. Background Theories

4.1. Overview

Portfolio theory (PFT) rests on a number of assumptions. The decisive works include (Markowitz, 1952) and (Markowitz, 1959). Elton and Gruber (1977) provide a very digestible perspective on key issues. Goetzmann (2010) provides an outstanding and far more complete summary of PFT issues than offered in this paper. Rather than burden the reader and given our objectives, we move to the fundamental ideas and connections, first with respect to statistics, then in terms of financial assets, and finally, in the context of our application.

4.2. Statistics

Thinking in terms of two variables is adequate for us to grasp the concepts. Combing two random variables (x,y) having expected values and corresponding variance (σ_x^2, σ_y^2) in expected values results in a simple weighted expected value. One chooses the weights (w_x, w_y) for each variable, these weights representing the fraction of each dollar in the particular asset. The weights total 1.0. With just two variables, *the weight not in **x** must be in **y***. Hence, if one chooses w_x, then $w_y = (1 - w_x)$. The expected value for the portfolio is,

$$(1)\ \ \textit{Expected Value}\ E(r_p) = w_x E(r_x) + w_y E(r_y)$$

Allow the expected values of the variables to have a *particular* correlation, $\rho_{x,y}$. As usual, the correlation coefficient ρ might range from +1 to -1. The expected variance for combining variables is:

$$(2)\ \ \sigma_p^2 = \sum_{x=1}^{n}\sum_{y=1}^{n} w_x w_y Cov(r_x, r_y)$$

Where $Cov(r_x, r_y)$ represents the covariance of expected returns of x, y.

With two variables, (2) simplifies to

$$(3)\ \ \sigma_p^2 = w_x^2\sigma_x^2 + w_y^2\sigma_y^2 + 2w_x w_y Cov(r_x, r_y)$$

Because covariance and correlation enjoy this relationship:

$$(4)\ \ Cov(r_x, r_y) = \rho_{xy}\sigma_x\sigma_y$$

We can rewrite (3) as:

$$(5)\ \ \sigma_p^2 = w_x^2\sigma_x^2 + w_y^2\sigma_y^2 + 2w_x w_y \sigma_x\sigma_y\rho_{xy}$$

Given any choice of weights (w_x,w_y), the *maximum* variance for (3) occurs when all the values are positive and maximized. The combinations of the squared terms and the fact that the weights are positive makes the first two terms positive. Thus (3) *has positive maximum value if $\rho_{x,y}$ is +1.0.*

4.3. Finance

Markowitz made the association to application by thinking of the effects in terms of financial and other assets. For example, one might think of a prospective investment opportunity and characterize the potential outcome in terms of its expected return and the variance of the expected return for a time period, e.g., daily or monthly.

Second, sensing what presumably many had overlooked, *he recognized that the expected returns of assets for a given period are likely always something less than perfectly positively correlated.* If the correlation coefficient is less than +1.0, then the variance of the combined variables *must be less than the maximum in (3).* The core conclusion: combining assets having less than perfectly correlated returns:

- Keeps the expected return as a simply weighted sum of the individual expected returns.
- Results in the variance of the return of the portfolio being less than the maximum.

Having nothing magical occur in terms of expected returns of a portfolio, *but reducing the expected risk of its returns offers benefit.* The risk eliminated or "diversified" away gained the label of unsystematic risk (U-risk) or asset (e.g., stock) specific risk. Any undiversified U-risk plus "systematic" risk (S-risk) represented the expected risk that remained in a portfolio following diversification efforts. The elegance of Markowitz's developments included the Min-Max criteria: minimize expected risk given an expected return; maximize expected return given a level of risk.

Complete or "perfect" diversification implied the elimination of all U-risk, with only S-risk left. Conceptually, that perfectly diversified portfolio at a moment in time represented ownership or the correct weights of all assets of risk that exist at that moment – characterized by some as the "market portfolio."

With more than two investments, one can portray the correlation/covariance relationships in a matrix. Rather than address this in detail, the Appendix offers a sample of this.

Many other developments as well as the normal degree of arguments and questions have resulted in numerous contributions to the literature. One finding is of special relevance for this paper. Statman (1987), building upon on the prior work of Evans and Archer (1968) as well as Elton and Gruber (1977), shows that the risk of a portfolio falls precipitously as new securities are added to the portfolio but quickly levels off after the addition of only around 20-30 securities. The securities added are chosen randomly. These findings illustrate that the elimination of unsystematic risk occurs fairly rapidly, and requires only naïve diversification. We know that the risk of a portfolio depends on the proportions of the individual stocks along with their variances and covariances. If the securities were to be chosen carefully with respect to those characteristics, it is possible to eliminate unsystematic risk even more quickly. Those studies suggest that selecting the right securities to combine in a portfolio results in a rapid diversification effect using a relatively small number of securities. Fig. 2 illustrates this effect without great detail.

<<Position of Fig. 2.>>

Fig. 2. Diversification of unsystematic risk with increase in number, n.

5. Application – Non-Financial Assets

5.1. Portfolio Theory, Capital, and Demand Fulfillment

PFT generally proceeds in terms of financial assets characterized with two specific parameters, the expected return on an asset, and the standard deviation of that expected return. Since our interest resides in finding incremental benefits from servicizing, we take an alternate approach.

First, rather than think in terms of expected financial returns and variance in those returns for securities, instead think of expected demand for units of service and variance in those expected demands for service. Some illustrations of Expected Service Units used (and the variance in those units) rather than the expected value of returns for financial assets includes:

- Call servicing. Calls demanded and length. Affects segmenting customers according to time zones, products and services about which they call to grant access to a particular call center based on individual demands having low correlations.
- Wi-Fi bandwidth demand. Affects grouping of customers whose demands are less correlated and assigning them to a particular point of access.
- Medical clinic service. Expected patient visits at a particular location. Assignment of patients to primary clinic based on their demands being less correlated.
- Data processing. Expected demand for CPU and processing time, again grouping customers based on low correlations in demand and assign to a pool to provide service.
- Order processing, payment and records processing. Expected time to complete.

Next, the results of studies of the risk of portfolios of securities depicted in Fig. 2 offer implications. Relatively few random variables yield potential great benefit in risk reduction. Hence, comparatively few participants making a service demand on an asset use "pool" that are less than perfectly correlated offer the prospect of significant benefit: lower variance in demand for services. Lower variance means one can better predict when clients will call for units of service, and have fewer assets in place to provide those services. Forming the right "membership" in an asset pool is akin to forming the "right" portfolios of securities – except in some cases with some additional, practical constraints.

The nature of the assets providing services and the demand for services from an "asset pool" or portfolio may call for additional constraints (such as geographical) in selecting those eligible to demand services from a particular "asset portfolio." For example, the demand for forklift use in Camden New Jersey will not benefit from inclusion of a demand agent in Los Angeles. In contrast, the demand for computational services from an asset portfolio of computational capacity likely will benefit from demand agents scattered about the globe with individual member demand sensitive to local time-zone dependent demands.

Demand may vary geographically due to seasonal impact. Tillage, nurture, harvests, and process machinery demand varies by geographic location due to weather and farming seasons – and attendant planting decisions. Some machinery does "move across" geographic zones to meet time and weather-dependent demand. Separate from more optimal use of equipment, asset pools provide the ability to concentrate multiple units on the rapid harvest of crops having harvest value (and risk exposure) sensitive to short time windows. The quality and value of crop – as well as yield and loss – are sensitive in crops such as vegetables for harvest and processing. For example, harvesting wheat at the optimal point of time affects moisture content, harvest loss, and the period of risk exposure for wind loss.

Let's proceed with exposure of concepts and ideas that support application.[5] Sharing these also might provide research ideas for the reader.

- The expected demand and variance in demand is with respect to a *period* of time (microsecond, second, minute, hour, day, …). We have expected demand within this interval, variance in that demand, and in some complicated situations, variance in the interval. Dividing the summation of individual demands from different users of the service in a time interval by unit combined maximum available capacity during the same time interval yields an interval *efficiency* utilization measure, useful in examining resource use efficiency.

- The behavior of interval demand and variance across a time period represents a time-series. Time-series analysis has special importance in the case of seasonality. Separately, potential shock demands during a period hold attention, e.g., a disaster and the demands for emergency services, blood, etc. The summation of this time-use-efficiency measure across a longer time period provides a longer term measure of asset use. Using a year as an interval makes sense given the frequent use of yearly economic returns. Summation of the incremental measures across tangible asset life offers an indication of the efficiency of resource use.

- Each potential user of the service has an *expected* demand or use against a "pool of services or asset pool" during a time interval. The unit for the interval is time: the length of time chosen for an interval depends on a number of factors. As an example of the variables involved in interval selection, the time unit for the bean harvest example depends on: units available; harvest rate/unit; unacceptable time of day harvest (e.g., no harvest during hottest six hours of day to limit post-harvest product damage); average crop acreage at a location in a region; unit relocation time; planting time of that acreage. The collective effects of these factors might argue for six-hour interval blocks. Given interval definition, the interval variance in expected demand for that user is var_{dit}, with the subscript *dit* reflecting expected demand *d*, over interval defined by *i*, and with time series *t*. Allow us to defer detailed discussion of these factors to a separate paper, "Selection of Demand Interval in Asset Pool Management" which will offer quantification and illustrations employing these notions.

- The capacity of the pool to satisfy the expected demand of those allowed to claim use of pool service units affects the capital invested in the pool. Malfunction of the units in the pool providing the service and the correlation of faults across units influence the decision on how many units to hold in the pool to provide the service.

- The acceptable stock-out or no-fill probability of providing service units from the pool influences units invested in the pool.

- Value creation and sustainability both benefit from achieving the same expected benefits with less capital employed (and at risk). Availability of servicizing units is one parameter to measure as a gauge of pool performance.

- In the normal context of PFT, one characterizes demand from different demand agents within the same time interval.

- One can examine cross-time correlation for *different* time intervals – unlike the application to financial portfolios that generally think of expected returns of each asset tied to the same time period. These circumstances might arise when the nature of demand functions against the pool are seasonal. Such changes might occur in demand for construction equipment services – and result in geographic redeployment of assets to pools in other regions. We will term possible benefits from this scenario as deviant portfolio benefits.

- Seasonal change of expected demand is different in focus than interval demand. Plans for pool inventory levels relate to differences in expected seasonal demand. At the same time but with a different focus, one gives attention to analysis of demand behavior during a particular interval, e.g., within a twenty-four hour period. Hence this does not represent traditional time series since the characteristics of the statistical distribution may differ across successive periods.

- Pool-managed versus physical dispersal of assets is still another potential harvest from portfolio effects. Units of the assets might be dispersed into sub pools, but the pools collectively managed as one pool. A whole blood supply represents an example.[6]

- Cross-user planning and optimization in the use of asset pools offers potential savings in costs and reduction in collective invested capital.

5.2. Asset use versus maintenance of assets in the pool

Selling the rights to asset use from the pool offers a different revenue stream from the costs charged for drawing service units from the pool. Additionally, asset use demand differs from maintenance and operating costs of the units in the pool. Naturally, the servicing of assets in the pool in terms of preventative, operation, and corrective repair affect the true availability and reliability of pool assets to meet the "portfolio of demand users."

Implications exist for the asset pool product/service provider in terms of capital invested in the pool, attendant revenues, and costs. The owner of assets in the pool may enjoy advantages and efficiencies in terms of purchasing power, efficiency of labor, and other economic factors that stem from economies of scale. These can lower the cost of providing a unit of service from the pool to the users – but these benefits are separate from any PFT derived benefits. However, PFT benefits may exist including a reduction in investment attendant with the maintenance function. For example, the portfolio effect will result in a lower inventory of spare parts to support a pool of assets.

Maintaining assets in the pool (separate from demand of asset) entail costs. Separate from economies of scale related to maintenance of units, the pool has fewer total units to maintain compared to individual ownership of units. This can reduce maintenance costs.

6. Moving to Applications

6.1. Shortfall and stock out/no-fill

We use these terms to indicate that the pool cannot provide the service unit at the time of demand. PFT can reduce stock out rates.[7]

6.2. Invested capital total (ICT)

Refer to Fig. 3 and note that the examples in this section are linked to the real cases briefly described in Section 2.3. For simplicity, *without a pool of assets* assume each company A, B, … has set invested capital (ICA, ICB, …) to attain the same probability of shortfall P[SF] in filling demand. For convenience – not necessity – we set the P[SF] at the same level for each company. The separate IC's for each company as well as sum of these amounts (ICT) appear in the top half of Fig. 3, for the case when expected demand for asset use *has perfect positive correlation* across companies: no magic.

The bottom half of the figure represents the instance when demand across companies enjoys $\rho < 1$. Then the pool of assets requires less ICT for the same P[SF] since the portfolio effect reduces the variance in net demand. The lower variance allows one to reduce the assets in the pool and still have the same P[SF].

<<Position of Fig. 3.>>

Fig. 3. Correlation of demand, total invested capital, and stockout.

To construct a simple example to support discussion[8], assume the ICT to sustain an expected demand of asset use of X with P[SF] is:

ICT = 100 units, ***without*** the application of PFT methods
ICT = <u>76</u> units, ***with*** application of PFT methods
24 units unnecessary capital at risk (UCAR)

The lack of perfect correlation of demand results allows less ICT with the same P[SF].

Alternatively we can examine the risk-reducing effects of pooling using a simple example. We examine the risk/return characteristics of pooling units versus distributing them between two operating Divisions A and B as shown in Table 1. We combine the risk (σ) and average measures by using the Coefficient of Variation, defined as:

(6) $$CV = \frac{\sigma}{\mu}$$

which provides a measure of risk per average unit of demand or capital employed.

Table 1. An example of risk-reducing effects

Year	Division A units	Division B units	Pooled units
1	10	8	18
2	15	12	27
3	7	15	22
4	11	13	24
Mean	10.75	12	22.75
Standard Deviation	3.304	2.944	3.775
Coefficient of Variation	0.307	0.245	0.166

Clearly, both Division A and Division B have variable demand for invested capital from year-to-year. Notice, however, that the risk per unit of invested capital as measured by the Coefficient of Variation is much lower for the overall pooled demand than for either Division A or B by themselves. This illustrates a key characteristic of PFT: Adding “risky” or uncertain assets together results in a portfolio that is less risky than either asset alone as long as demands are not perfectly correlated.

6.3. Implications for Capital and Sustainability

Eliminating UCAR (unnecessary capital at risk) is important in the context of valuation and sustainability. Furthermore, if we can generate incremental returns (not traceable to a portfolio effect, but to other opportunities), we can gain increments in value. In valuation, we have several core sources of expected benefits, falling into one of these categories.

Invested capital, returns, and risk issues. Reducing the *amount* of capital and/or the risk exposure of capital used to support a given level of operations are important in the context of common measures of the efficiency of capital use, returns, and value creation. Considering the patience of the reader, we defer details to future papers. However, the potential includes:

- The same expected benefits with the same P[SF], with less invested capital.
- Increased expected benefits from more efficient use of assets, while maintaining the P[SF]).[9]
- Increased return on capital employed.
- Reduced capital exposed at risk.
- Less capital required to support growth in demand.
- Reduction of lost capital, this stemming from less capital exposed to various risks such as obsolescence, economic depreciation, and other factors.

6.4. Sustainability

Using less capital to achieve the same beneficial effects is a core principle in sustainability. Garnering a portfolio benefit offers the prospect of:

- Reduction in the capital consumed to provide need fulfillment – a critical issue in sustainability for non-renewable resources.
- Greater need fulfillment relative to the use of resources.
- Favorably altering the Need Fulfillment to Resource Use Ratio (NFRU), both by changing the numerator and the denominator. In efficient markets, more efficient use

of capital reduces the cost of capital subsequently captured in the costs of goods and services – with the attendant reduction in the costs of need fulfillment. This is a numerator effect. Reduction in capital consumed results in a reduction in costs that results in both a denominator and numerator effect.

- In efficient markets, achieving greater efficiency in the use of assets distills a lower cost of financial capital with attendant increase in value.

6.5. Pool Management Strategy

Managing a pool of tangible assets to meet user demand involves an array of issues.[10] A brief highlight of some includes:

Critical time obsolescence. Assets that are critical in supply or that have high social or economic costs, and/or that have diminishing value with time offer potential benefits from asset pool management. A whole blood supply pool is a perfect example.

Collars and maximum draw. One can set the minimum and maximum allowed demand for service units by a company using the pool. The collars and maximum draw can exceed (if portfolio benefit is present) the individual user's ability to meet demand using in-house assets rather than the pool. This yields a benefit to the user by reducing user demand stock-out risk.

Manager penalties. Other variants include, e.g., max variance allowed/tolerated by an individual pool user and, guaranteed availability to a user with a predefined penalty paid by the pool manger if the pool cannot fulfill the demand.

"Overdrafts" and charges. One might set maximum draws allowed in an emergency, with attendant incremental costs to the user that exceeds the collars. This is essentially users buying "insurance" rather than keeping backup assets in house.

Pool membership. Even though a large number of users may exist for demand of a particular service, one may find it better to form more than one servicing pool. Common sense might dominate over the incremental PF benefits of putting everyone in the same pool. Concerns about having too large a single pool (e.g., thinking in terms of a bank that is too big to fail), geographic issues if service has a transportation and/or time dimension might suggest separate pools. Separate pools could choose to assist another pool while avoiding compulsory assistance.

Cross-seasonal demand. Seasonal demand issues extend beyond the normal seasonal calendar. Significant PF benefits to servicizing likely stem more from within-day variance of demand, with individual user demand tied to the local clock for the "process time."

Time-dependent demand. PFT for securities relates to the behavior of the individual assets with respect to the same period of time, e.g., daily, monthly returns. In our application the relationships are not exactly in concordance with the assumptions of PFT, e.g., expected period returns. Nevertheless, in a practical sense we can benefit from the notions of PFT, admitting these are deviant (but practical) rather than pure portfolio benefits.[11]
The demand for use of an asset/service may vary at the same moment of time, or within a relevant period, e.g., a day. A reservation center is an example, with demand varying greatly at specific times in an interval, as well as within a calendar day – with same time demand (ST) as well as within-day demand (WD) jointly influencing demand on the pool. One might

create subsets of demand customers that have access to the asset pool only during specified periods, referring to these groups as segmented demanders. Creating a particular array of segmented demands having time specific windows of claim against a resource pool offers additional possibilities.

Cross-pool management. For certain types of assets or claims on service (e.g., information processing), managers of different pools might gain additional benefits by limited coinsurance of demand across different pools of assets.

Aberrant or derivative portfolio benefits. This notion stems from the fundamental difference in the application of portfolio theory to non-financial assets and services rather than financial assets. Efficiency in the access and use of assets to fulfill need fulfillment might (likely) changes actual demand functions as well as cost structures, ease of entry and competition, and other factors.

6.6. Ideas for Research

The length of the paper, respect for the patience of the reader, and comments of a reviewer argued for deferring details on coverage and example of application to a second paper. However, at this stage we offer qualitative examples.

- Operating call centers (as some do now) with potential demand for service units (callers seeking help) provided access (with phone numbers or other forms of communication) based on the lack of correlation of demands. This offers portfolio benefits within the pool(s) and also, in terms of service demands for the separate pool(s) providing the communication services.
- Blood bank pools with the intent of maximizing availability while minimizing blood units expiring.

Paper two in the series, “Resource Employment, Efficiency, Risk, and Sustainability: Portfolio Theory Applied,” will move from theory to application. The scope of the second paper includes:

- An illustration of the calculation of the variables to support application.
- Identification and selection of the logical “weights” to employ in the portfolio calculations.
- Determination of the correlation values.
- Setting portfolio allowable variance.
- Reporting the results of calculations for a sample of demand agents sequentially added to the pool, to reveal the incremental effects of forming a pool as well as the benefits of particular demand agents joining the pool.
- Determining the aggregate effects of multiple demand agents participating in the pool.
- Illustrating the practical approach to setting targets and limits in terms of stockout probability.

- Showing with example the reduction in resources used, attendant with maintaining the same probability of stock-out.
- Estimating the dollar value benefit of reduction in resource utilization.
- Discussing and illustrating the dollar impact of benefits as a function of asset *unit* value.
- Illuminating additional ideas for application.

A sample of potential avenues for additional research includes:

- The use of PFT in the selection of demand agents that can claim use of an asset pool. This is separate from the portfolio effect in the pooling of assets.
- The optimal physical dispersion of physical assets to meet demand.
- PFT and the design of products and critical faults.
- Optimization of resource demand-use for expiring resources, e.g., demand-use of power on a grid.
- Management of high-value, critical-value, and expiring resources in "shared asset pools," e.g., human whole blood inventories at multiple physical locations. In this application, one manages the physically dispersed units as a portfolio.
- Mass Customization (MC) (Pine, 1993) and its influence on economies and the environment offers an array of interesting future works (Sakao and Fargnoli, 2010). A company employing MC keeps different modules "in inventory" to use in response to demand of a customized product. In principle, the level of need fulfillment is higher with MC than mass production of standardized products. On the other hand, the quantitative influence of MC on the resource employed/used warrants investigation.
- The NFRU reflects the success at fulfilling human needs relative to the resources employed and/or depleted in the process.[12] Providing a desired level of light employing/depleting the lowest resource use represents an example. Tailoring a product or service to better match individual desires and preferences in need fulfillment relative to resource use are another example – and an example of potential benefits of Mass Customization – as a measure of resource use efficiency and sustainability.
- Servicizing and Use versus Ownership: Implications for Marketing examines derivative marketing implications that result from the user of the product/service being different from the owner/provider. For example, in the case of car share, decisions related to fueling, servicing options, tire replacement and similar purchase decisions do not rest on user decisions.

7. Conclusions

Our admission is that the grand task is incomplete. Readers will have additional and new ideas to feed development. Inter-disciplinary work has challenges since people have core knowledge in their own disciplines. Exploring, sharing, and working together will allow us to benefit from the contributions of the disciplines and offer the perspective and leverage of the "bigger" picture.

The concepts and implications of portfolio theory (PFT) offer opportunities outside of the finance field. In particular, the "pooling" of assets/services to meet uncertain demands from different users of an asset/service pool may yield benefit from diversification effects. Those benefits include a reduction in capital employed to fulfill customer needs, more favorable costs structures, a change in total net demand, and derivative benefits to sustainability.

The paper has raised issues, offered perspectives, and suggested avenues for additional research. Special application of portfolio theory outside the realm of pure finance will yield benefits that affect the creation of value in an economy. In particular, this paper provided insights and lent support to how portfolio principles applied outside the arena of investments can affect:

- Invested capital required to support a business process.
- The magnitude and impact of idle capital.
- The opportunity to reduce idle capital with attendant benefits.
- The potential loss of capital, of special concern if capital is perishable and/or subject to obsolescence.
- Risk, returns, and resultant value creation.
- Special benefits that may stem from application in the "service inventory" as well as for tangible units of input, process, or product.
- The favorable impact of portfolio theory and wise choice on sustainability.
- Increased returns on financial and tangible capital.
- Improvement in the **Need Fulfillment to Resource Use Ratio**, in support of sustainability.
- The positive impact on the efficiency of human capital.

To the extent we have stimulated thoughts and provoked debate and future explorations, we have achieved a key objective. The promise and expectation of benefiting from appreciating and harvesting from multiple disciplines attracts us. Different disciplines have their "own crayons." We suspect that the beauty of art stems from all the brush strokes collectively offering insights and perspectives. This paper illustrates how portfolio principles applied outside the arena of investments can yield benefits, including the fulfillment of needs with the least resource used – a core principle in sustainability. This special application of portfolio theory outside the realm of finance can yield benefits that positively affect the creation of value and resource use in an economy at large. We look forward to readers joining us again for paper two in the series.

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9. Appendix

Computation of Portfolio Variance for Portfolios with More Than Two Assets

The portfolio example in the paper used two assets for simplicity. Using a matrix, it is not difficult to calculate the portfolio variance for more assets. The matrix below illustrates a covariance matrix for the returns of three assets, X, Y, and Z.

Bordered Covariance Matrix

Portfolio Weights	w_x	w_y	w_z
w_x	$Cov(r_x, r_x)$	$Cov(r_x, r_y)$	$Cov(r_x, r_z)$
w_y	$Cov(r_y, r_x)$	$Cov(r_y, r_y)$	$Cov(r_y, r_z)$
w_z	$Cov(r_z, r_x)$	$Cov(r_z, r_y)$	$Cov(r_z, r_z)$

The diagonal of the matrix represents the covariance of an asset's returns with itself, i.e. the *variance* of asset returns.

To illustrate use of the matrix to calculate the portfolio variance, we multiply through by the weights on the matrix border.

Border-Multiplied Covariance Matrix

Portfolio Weights	w_x	w_y	w_z
w_x	$w_xw_xCov(r_x, r_x)$	$w_xw_yCov(r_x, r_y)$	$w_xw_zCov(r_x, r_z)$
w_y	$w_yw_xCov(r_y, r_x)$	$w_yw_yCov(r_y, r_y)$	$w_yw_zCov(r_y, r_z)$
w_z	$w_zw_xCov(r_z, r_x)$	$w_zw_yCov(r_z, r_y)$	$w_zw_zCov(r_z, r_z)$
$w_x + w_y + w_z = 1$			

The portfolio variance results from summing the covariances:

$$\sigma^2_p = w^2_x\sigma^2_x + w^2_y\sigma^2_y + w^2_z\sigma^2_z + 2w_xw_yCov(r_x, r_y) + 2w_xw_zCov(r_x, r_z) + 2w_yw_zCov(r_y, r_z)$$

This technique for calculating portfolio variance is easily adapted for any number of assets and is ideally suited for spreadsheet use.

10. Vitae

Dr. Steve Byers is a professor in the College of Business at Idaho State University. He received his Ph.D. (Finance) from Texas A&M University. He also holds a degree in mathematics and an MBA in finance, both from Indiana University. He teaches graduate and undergraduate courses in investments and corporate finance. His research has been published in academic journals such as Journal of Money, Credit, and Banking, Journal of Corporate Finance, European Business Review, and Applied Financial Economics. Steve has corporate finance experience with NCR Corporation and Bristol-Myers. He also served in the U.S. Navy as a nuclear submarine officer.

John C. Groth – Emeritus Professor of Finance, Mays School, Texas A&M University. PhD, Krannert School, an M.S.I.A, and a degree in physics. Awards: Distinguished Fulbright – 2002, Mays Faculty Fellow for Teaching Innovation; University Faculty Distinguished Achievement Award in Teaching, and many others. Heck and Cooley cite him as a "Most Frequent Appearing Authors in 26 Core Finance Journals." Interdisciplinary papers appear in Creativity & Innovation Management, Journal of Accountancy, Journal of Consumer Marketing, Journal of Product & Brand Management, and other journals. A retired naval officer, O-6, he had three commands, served as a chief engineer. In 2011, he was inducted into the Purdue University ROTC Hall of Fame for contributions in military and civilian careers.

Tomohiko Sakao has been professor at the Division of Environmental Technology and Management, the Department of Management and Engineering, Linköping University, Sweden since 2007. He has been a visiting researcher at the University of Tokyo and at Technical University of Berlin since 2002 and 2009, respectively. His research interests include Ecodesign and Integrated Product Service Engineering. He served as a lecturer of a dissemination program of environmental business by METI (Ministry of Economy, Trade, and Industry), Japan in 2004/5. He was an awardee of research fellowship by the Humboldt Foundation at Darmstadt University of Technology, Germany from 2005 to 2007.

11. Figure Captions

Fig. 1. Need fulfillment in different ways of using resources.

Fig. 2. Diversification of unsystematic risk with increase in number, n.

Fig. 3. Correlation of demand, total invested capital, and stockout.

12. Figures

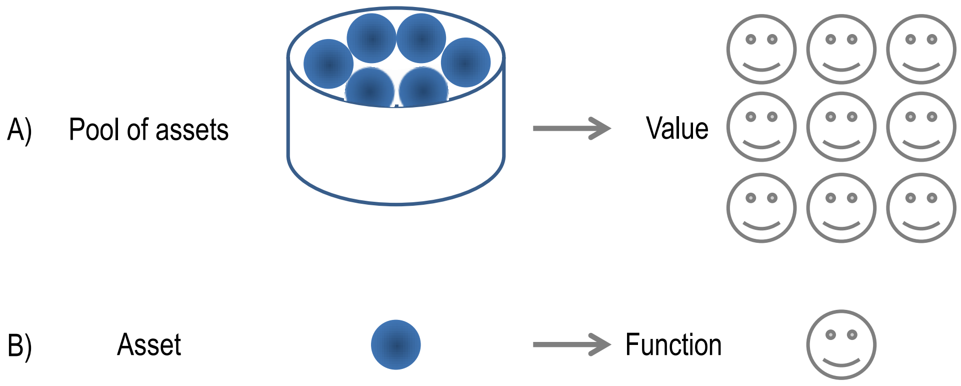


Fig. 1. Need fulfillment drawing from pool vs. individual unit use.

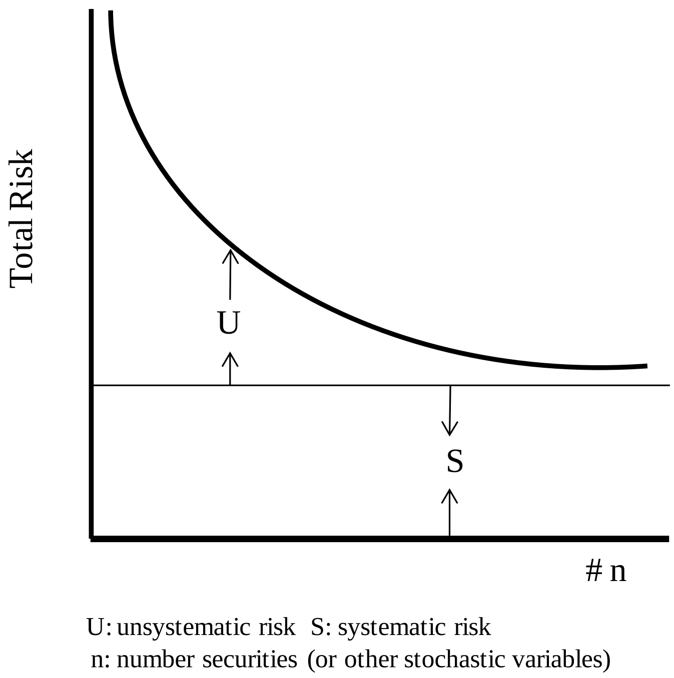
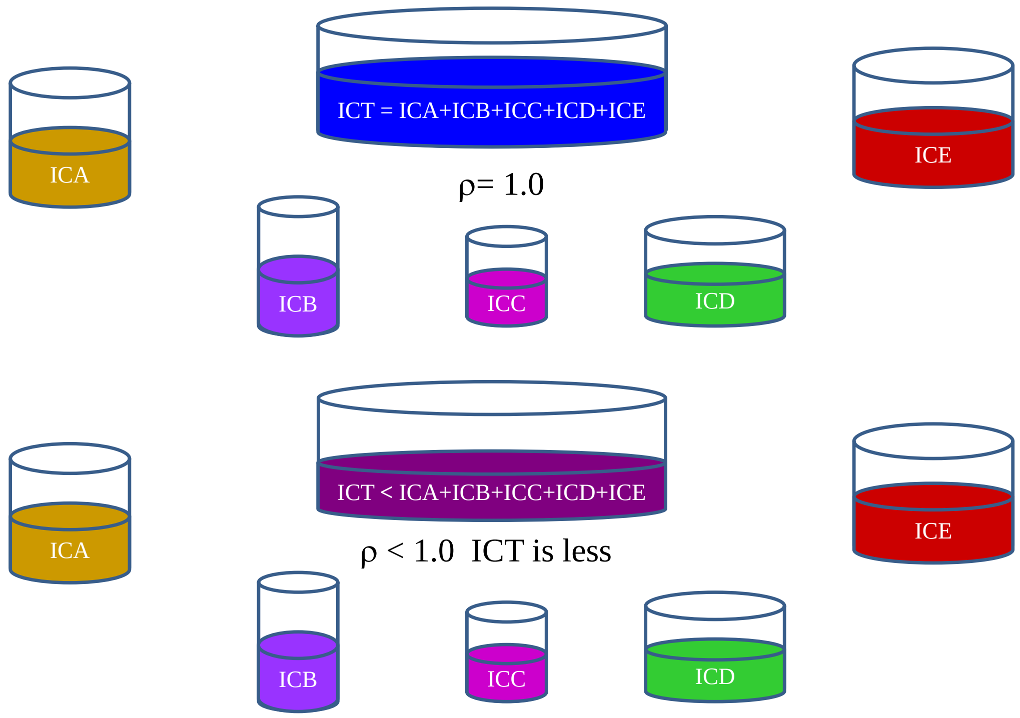


Fig. 2. Diversification of unsystematic risk with increase in number, n.



For a given probability of no fill of demand: Total invested capital if demands A, B, C, D, E $\rho = 1.0$ & if $\rho < 1.0$. ρ is correlation of expected demand. IC = invested capital and ICT is total invested capital.

Fig. 3. Correlation of demand, total invested capital, and stockout.

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[1] Careful development of human capital offers the potential of increasing, rather than merely sustaining, human capital. A separate paper will address core issues in this area.

[2] Sometimes one can recover (e.g., financial capital) or replace (e.g., grow a new tree) capital and “use it again.” In contrast, capital “used up” (e.g., a person’s time, talent or a barrel of oil) is gone forever. Employing, recovering, and redeploying capital is incredibly different from using up capital – and contributes to sustainability..

[3] Portfolio theory has application in quality control, redundancy, design, critical fault, medical treatment, weapons deployment, trials and analysis, automated analysis and other areas. Some of these topics are the subject of research by one or more of the authors.

[4] http://www.hondadiracc.com accessed on March 7th, 2008.

[5] Many of the concepts and ideas in this section each call for a separate to offer detail. We already greatly shortened this paper at the suggestion of reviewers.

[6] Groth and Flores gave attention to this. See Groth, J.C., Flores, B.E., 1989, Global Critical Product Management System, 27th Annual International Atlantic Economic Conference, Barcelona.

[7] Another paper will give attention to special applications of PFT in quality control as well as in safety, product and system design, redundancy, and related issues.

[8] Not a calculation using actual correlations etc.

[9] This represents a potential benefit *not* thought available in the context of financial securities. The expected return of a portfolio of securities is simply a weighted average.

[10] “Pooled Asset Management: Implications of Demand and Asset Characteristics” hold interest for a future paper.

[11] We recognize that one can shorten the period for examination of demand against the asset pool, in extreme to the limits. In a practical sense, the shortest unit of time is the minimum time usage a customer of the pool can use the asset to achieve benefit. We defer the mathematics of this to another occasion.

[12] Efforts to fulfill needs may employ (with recoverability) and/or deplete resources in the process. For brevity, we will use “resource use” meaning both use and or depletion.