# Cost Allocation Strategy Report

(Draft - for discussion only)

*The very proposal that costs be allocated implies that it is impossible to say who caused them to be incurred.*[1]

## What is cost allocation?

Cost allocation is the process of distributing the costs of a multi-purpose project among the various purposes served. The cost allocation process becomes an issue when a project includes features that serve more than one purpose. The cost of such features is known as a joint cost, and the essential problem of the cost allocation process centers on the distribution of joint costs among purposes served. The goal is to develop a method that allocates these costs equitably among purposes served.

It is important to make a distinction between cost sharing and cost allocation. Cost allocation distributes the costs of the program to different purposes, or uses. It does not tell you how much individual users, agencies, or beneficiaries will pay. This decision of how much individuals will pay, usually a political one, is made without any scientific methodology. More often than not, cost sharing is negotiated. For example, assume you will build a dam. It is determined that the dam will provide benefits for water supply, flood control, fisheries, and recreation. Cost allocation is the process that will iron out how much of the total cost of the project that each purpose will have to pay. Cost sharing will determine exactly how much the different beneficiaries of each purpose will pay. Keeping with our example, let us suppose that we find that flood control will have to pay 20% of the entire cost of the project. This is the cost allocated to flood control. Of this 20%, it is decided that the federal government will pay for 65%, with the remaining 35% of the cost paid for by local sponsors. This 65/35 split is the cost share of the flood control portion of the project.

This problem of allocating costs is not a new one, with methods dating back to the Tennessee Valley Authority (TVA) Act in 1933. Still, there is not one universally accepted cost allocation method. In fact, there are more cost allocation methods today than there were back in 1933. In 1954, an inter-agency agreement on cost allocation between the Department of the Interior, the U.S. Army Corps of Engineers, and the Federal Power Commission agreed that there were three acceptable methods of cost allocation: the separable costs-remaining benefits (SCRB) method, the alternative justifiable expenditure (AJE) method, and the use of facilities (UOF) method. Since 1954, there has been research done on the application of Game Theory to cost allocation. Two examples of game theoretical cost allocation methods are Shapley Values and the Nucleolus.

## How does this relate to CALFED?

While there are many disagreements about exactly what CALFED should do, there is no doubt that *something* must be done. We must move forward. In order to

[1] L. Douglas James and Robert R. Lee, Economics of Water Resources Planning, p 529, (New York: McGraw-Hill), 1971.

successfully implement the program, somebody has to pay for it. While a preferred alternative has not yet been chosen, *every* alternative *must* address six elements, called the common programs: water use efficiency, water transfers, ecosystem restoration, watershed management, water quality, and levee system integrity. It is evident that no matter what CALFED does, it will be a multi-purpose program, and, as such the costs will need to be allocated.

The allocation of costs becomes crucial because recovering the costs of the program is not the only factor in the success of the program. The cost allocation methodology must be equitable. If people do not think the allocation of costs is fair, then they won't buy into the CALFED solution. At the same time, however, it is important to realize that not everyone will be happy with the final solution, nor will everyone be happy with the final allocation of costs. There is no cost allocation method that will make everyone happy. Without a successful financial package, however, the time and work done by CALFED staff will all be for naught. In addition, many stakeholders consider the funding of the program to be a potential "deal-breaker". It is for this reason that the different cost allocation methodologies must be analyzed carefully, so that a decision isn't made in haste at the last minute that might be a death sentence to the program as a whole.

**How will we choose a cost allocation method?**

Since there are many different cost allocation methods, there has to be a way to evaluate them and make a decision. The Bay-Delta Advisory Council (BDAC) Finance Workgroup chose certain criteria with which to judge the different cost allocation methods. No cost allocation method is perfect, and each method has its own strengths and weaknesses. It is important to remember that *there is no single best method that will optimally address all of the issues.*

| Criterion | Description |
|---|---|
| **Consistent** | The costs allocated to a purpose should not change based solely on how the other purposes are subdivided or aggregated either initially or over time. In addition, effects of cost changes over time on the allocations to each purpose should be predictable and rational. For example, increases in total project costs should not lead to cost allocation reductions for some parties at the expense of larger increases for others. Costs allocated to the federal government related to ecosystem should not change based on whether all users are grouped together or treated separately as urban and agricultural. |
| **Fair** | All purposes and beneficiaries are treated the same in terms of receiving a reasonable share of the savings from the joint project. No special rules or calculations should be employed that would result in special treatment of a particular purpose. Joint projects are pursued because it is less expensive than pursuing separate projects to gain the same benefits. The crux of the allocation issues relates to joint costs: those that cannot be traced to a specific purpose. One way to look at the allocation issue is how to share the savings of the joint project versus the separate projects. |

| | |
|---|---|
| **Flexible** | The allocation method must enable addressing issues for a diverse mix of projects and programs that each may raise different issues. For example, must the methodology enable addressing the issues of fish screens, flood control measures, and recreational benefits? Each of these raises some specific issues. |
| **Inexpensive** | Using the cost allocation methodology should involve manageable costs for obtaining input data, performing cost allocation calculations, and developing results. For example, SCRB requires costing out a number of scenarios that are never intended to be built for purposes of defining separable costs. This can be expensive. |
| **Rational** | Ability to charge each purpose at least as much as the cost of inclusion, and no more than the cost of going it alone.[2] |
| **Reliable** | The allocation methodology must employ proven techniques. Proven techniques are those that have been employed previously by CALFED agencies or others in similar situations and have been demonstrated to produce workable results. |
| **Sufficient** | The cost allocation methodology should assure recovery of full project cost. Marginal cost approaches are not designed to recover a set amount of money, and could end up recovering more or less than the cost of the project. |
| **Understandable** | Ability to explain the methodology and results in a manner that enables widespread comprehension and support of the methodology. |

**Introduction to the various cost allocation strategies**

The BDAC Finance Work group chose six methods to be analyzed according to the established criteria described in the table above. There are three traditional methods, all considered acceptable since the 1954 federal inter-agency agreement.

- The separable costs-remaining benefits (SCRB) method is considered preferable for general application.
- The alternative justifiable expenditure (AJE) method is acceptable where the necessary basic data to determine separable costs are not available and the time and expense required to obtain the data are not warranted.
- The use of facilities (UOF) method is acceptable where the use of facilities is clearly determinable on a comparable basis and where use of this method would be consistent with the basis of project formulation and authorization.

The "Follow the Water" method will also be considered by the work group. This approach would use the overall use or consumption of the water resource as a means of

[2] For this analysis, "going it alone" will mean *without* current or future government subsidies. This will prevent giving unfair advantages to one group over another. For example, farmers "going it alone" would include the assumption that they would pay the market price of water. Ability to pay will not be a factor in the initial analysis, nor will it be a factor in the decision-making process of a preferred cost allocation method. These issues will be discussed and analyzed after a "first-cut" attempt at a cost allocation formula has been made.

allocating costs. Although there are many complex details associated with this approach, the basic concept is simple. Costs of the solution would be split among groups based on their proportional use of the water that flows into the Delta or would flow into the Delta but for being diverted.

There are two technical methods that are based on game theoretical research conducted over the past few decades.

- The Shapley Values result in an allocation based on the average price of all orderings for inclusion of purposes in a multi-purpose project.
- The Nucleolus approach is based on a repeated allocation of joint costs such that each pairing of two parties split the difference between the most and least favorable divisions to themselves holding other allocations constant, and maximizing the distribution of cost savings to each proper subset of parties.

**Traditional Approaches**

In 1954, an inter-agency agreement on cost allocation between the Department of the Interior, the U.S. Army Corps of Engineers, and the Federal Power Commission agreed that there were three acceptable methods of cost allocation: the separable costs-remaining benefits (SCRB) method, the alternative justifiable expenditure (AJE) method, and the use of facilities (UOF) method. Of these three methods, the SCRB is the most popular and widely used method of cost allocation. It is the only method used by the U.S. Army Corps of Engineers.

**Separable costs-remaining benefits (SCRB) method**

The separable costs-remaining benefits (SCRB) method of cost allocation is the most widely used method of cost allocation for multi-purpose water projects. With SCRB, each purpose in a multi-purpose project is assigned the separable costs of including that function in the project, plus some portion of the remaining joint costs. Separable costs include not only the specific costs of a purpose, but also the added costs of a change in the size or design of the project due to the inclusion of that purpose.[3] Joint costs are the difference between total project costs and total separable costs. Each purpose pays its own separable costs, and the joint costs are then allocated based on the remaining benefits of the project that accrue to each purpose. The proportion of joint costs that each function pays is the same as the ratio of the remaining benefits of each function to the total remaining benefits.

One of the biggest advantages of the SCRB method is that it enjoys widespread acceptance by both federal and state government agencies. SCRB has been used successfully on water projects, such as the State Water Project, so it scores well on reliability. If the SCRB method is the chosen cost allocation method, it is likely that this choice will be accepted without much challenge or opposition.

The main disadvantage with the SCRB method is that it can be quite expensive. It can take a lot of time to develop separable costs, especially if there the project has many

[3] Loughlin, James C, The Efficiency and Equity of Cost Allocation Methods for Multipurpose Water Projects, *Water Resources Research*, Vol. 13, No. 1, 8-14, Feb 1977.



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purposes. The SCRB also doesn't score well on consistency, mainly due to its non-monotonicity[4]. In other words, there are cases where an increase in total costs will cause decreases in costs allocated to some parties at the expense of other parties[5].

**Alternative justifiable expenditure (AJE) method**

The Alternative justifiable expenditure (AJE) method is very similar to the SCRB method. It works in much the same way, the only difference being that with AJE, specific costs are used for each purpose instead of separable costs. This method is considered acceptable when you don't have the necessary data, or the time or the available resources, to develop separable costs for each purpose.

The specific costs, unlike the separable costs, do not include the costs of a change in project design due to inclusion of the purpose. This has the advantage that the AJE method is much simpler to calculate than the SCRB method. It is also potentially much cheaper than the SCRB method. The disadvantage is that it might not be as accurate as the SCRB method, since specific costs do not reflect the total costs that a purpose might bring to a project.

**Use of facilities (UOF) method**

The primary difference between the Use of facilities (UOF) method and the SCRB and AJE methods is the way UOF allocates joint costs. Either the separable costs or the specific costs are first subtracted out, as with the SCRB and AJE methods. The remaining joint costs are then allocated based on certain physical criteria, rather than remaining benefits. Examples of criteria used to allocate joint costs with UOF are reservoir storage space, water flow, and energy consumption.

The UOF method is a good method when the benefits for a project are not easily computed. However, it is considered acceptable only when joint uses of a project are clearly determinable on a comparative basis. If joint uses are not comparable, then this is not a very good cost allocation method. It is often difficult to find a common denominator for all of the uses, so this method is recommended only in limited cases.

**"Follow the Water" (FOW) method**

The Follow the Water (FOW) method is similar to the UOF method, in that costs are allocated based not on benefits but on physical criteria, in this case water flow. Costs would be allocated proportionally based on the amount of water taken out of the system or water that was diverted before it had a chance to enter the system.

Some of the details of this method would need to be worked out, such as the quality of the water that is returned to the system, and how this would play a part in the charge given to a user. In order for this method to be truly equitable, some of the

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[4] Monotonic (from Webster's): having the property either of never increasing or of never decreasing as the values of the independent variable or the subscripts of the terms increase.

[5] Young, H. Peyton, Cost Allocation: Methods, Principles, Applications, p 17, (North Holland: Elsevier Science Publishers B.V.), 1985.



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externalities associated with returning diverted water to the system would need to be internalized.

This method appears to be equitable, because FOW doesn't care who is using the water. No special exceptions are given. If you use water, you pay. Also, because the cost allocation would be based not on marginal costs, but on a proportional allocation of total costs, it should be a sufficient means of allocating costs. It is difficult to determine whether or not the FOW method would be expensive. Presumably it would be necessary to have extensive metering to determine how to allocate the costs, so the initial costs of implementation would be expensive. Also, the formula would need to be evaluated and changed periodically to account for conservation and/or increased diversions. On the other hand, the whole process of determining separable costs would be unnecessary, which would save money.

**Innovative methods**

Over the past few decades, there has been substantial academic research on cost allocation. The intent of this research was to identify the weaknesses of traditional cost allocation and develop mathematical or logical models to overcome these shortcomings. The goal was to create better, more fair cost allocation methods. Game theory is the basis of these innovative methods. For a more in depth introduction to game theory and some of the language used with it, please see appendix 1 (page 11).

**Shapley Values**

In 1953, Lloyd Shapley looked at n-person game theory in a different way. His goal was to determine the value of a given game for a particular player. Given the characteristic function of a game, Shapley outlined a method for determining the worth of a game to each player. Hence, these "values" are called Shapley values. If you make the assumption that a coalition will form among all the players, the marginal gain that each player will get by joining the coalition versus not joining would be that player's Shapley value. In terms of cost allocation, costs would be allocated according to the average marginal cost of adding a use to a multi-use project.

For example, if you decide to build a reservoir, there may be different uses for it. Let's assume that 25% is for flood control, 50% for storage, and 25% for increased flows during off-peak periods for the environment. The Shapley Values would allocate the costs of this project by the increased (marginal) cost that each use would bring to the entire cost of the project. All possible orderings of inclusion of the uses would be taken into account, and the average marginal cost of inclusion would be that use's Shapley Value.

The Shapley Values is the only cost allocation method that is unequivocally consistent. It also scores well in terms of equity, sufficiency, and rationality. Like SCRB, the Shapley Values can be expensive, which is one of the few disadvantages with this method. Another drawback is that it might not be a popular choice politically, because some stakeholders don't trust its reliability.



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**Nucleolus**

In some games, there is an empty core. In other words, there are some coalitions that might be considered necessary, or better for society as a whole, but not everyone who is in the coalition will benefit by joining. The nucleolus can be helpful in these cases, because it will try to find a solution that is as close to the core as possible, even if it isn't contained within it. The goal of the nucleolus is to find the imputation that will make the most unhappy player or coalition as little unhappy as possible[6]. In other words, try to minimize the largest difference between what the player or coalition would gain independent of the grand coalition over what can be gained from the grand coalition. According to Josh Billings, "the wheel that squeaks the loudest is the one that gets the grease."[7] Using this analogy, the nucleolus tries to make the squeakiest wheel squeak as little as possible.

In terms of CALFED, this would mean that you would try to appease the least happy stakeholder. Costs would be allocated away from the least happy purpose to other purposes until no amount could be redistributed without making another stakeholder more unhappy than the original group would have been. This point, where no one stakeholder could be made happier without making another group more unhappy, is the nucleolus.

The advantage of the nucleolus is that it tries to make everyone equally happy. In theory, no one stakeholder group should be left to feel that another group is better off than they are. This would possibly help with the acceptance of the methodology, although it is a complicated mathematical formula, and probably would not enjoy widespread understanding. The nucleolus has not been used as much as some of the more traditional approaches, so its reliability is a question. The nucleolus is flexible, however, and could be used for a number of different projects. Finally, the nucleolus tries to take into account fairness, because the users who find a project the most unfair to them get some of the cost transferred away from them and onto someone else. All purposes and beneficiaries are treated the same. It doesn't matter whom the most or least powerful stakeholder is, because this is not a factor in determining the allocation. The nucleolus method is a "Robin Hood" approach. You take some from the rich and give to the poor until everyone is at the same level of utility. The power of a stakeholder is not taken into account, which is good from an equity standpoint but might not be the best feature politically, in terms of the eventual success of the project.

**Ranking of analyzed cost allocation methods**

For the first-cut attempt at ranking the cost allocation methodology, I used an equal weighting of the selection criteria. Each criterion was assigned a value from 1 to 5 for each method, with 5 being the worst. The cost allocation method with the lowest *total score* was selected. This simplistic analysis is by no means set in stone. CALFED might decide to prioritize the selected criteria. For example, if consistency were given a higher

[6] Straffin, Philip D. *Game Theory and Strategy*, p 202. New York: The Mathematical Association of America, 1993.
[7] Straffin, Philip D. *Game Theory and Strategy*, p 202. New York: The Mathematical Association of America, 1993.

priority than the other criteria, say 2:1, then the Shapley Values would be selected over the SCRB method.

Based on my admittedly simplistic ranking, I believe the SCRB method is the best method for allocating the costs of the CALFED program. However, this method is quite a bit more expensive than the AJE method, which is very similar. The Shapley Values also seems to be a good way to allocate costs. Indeed, it tied SCRB in the overall rankings, and it was the best method in terms of consistency. The Shapley Values method is not proven nearly as much as SCRB, however, and the near universal acceptance of the SCRB by all of the CALFED agencies makes it a more attractive method. The Nucleolus method rounds out the bottom of the list. It scored poorly mainly due to its difficulty to understand and to calculate, its reliability, and how expensive it would be.

**Selection of a preferred Cost Allocation Method**

In conclusion, I am recommending the use of the SCRB method to allocate the costs of the CALFED Bay-Delta program. This method is proven, and it won't make agencies as nervous as some of the "new mathematical" innovative methods. In addition, the SCRB is flexible and does a good job of equitably allocating costs to the different purposes of a program.

This recommendation comes with certain stipulations, however. Further research would need to be done to see if this method is economically feasible within our budget. It might be very difficult and expensive to create separable costs, and if this is indeed the case, maybe we should take another look at Shapley Values or AJE. In addition, the cost allocation criteria should be carefully examined and possibly prioritized. This could significantly change the outcome of which cost allocation method we choose. Also, the political and legal feasibility of the methods should be examined. If the criteria are prioritized and one of the innovative methods is chosen, this might cause uproar with some of the stakeholder groups and agencies, which are not comfortable with these new methods.



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**Table 1**

## Relative Rank of Cost Allocation Methods based on Selected Criteria

**Conventional Methods** | **Innovative Methods**

| | Separable Costs-Remaining Benefits (SCRB) Method | Alternative Justifiable Expenditure (AJE) Method | Use of Facilities (UOF) Method* | Use of Facilities (UOF) Method** | Shapley Values | Nucleolus | "Follow the Water" Method |
|---|---|---|---|---|---|---|---|
| Consistent | 4 | 4 | 4 | 4 | 1 | 4 | 1 |
| Fair | 2 | 3 | 2 | 3 | 2 | 1 | 2 |
| Flexible | 1 | 1 | 5 | 5 | 2 | 2 | 3 |
| Inexpensive | 5 | 2 | 5 | 1 | 5 | 5 | 3 |
| Rational | 1 | 5 | 1 | 5 | 1 | 1 | 4 |
| Reliable | 1 | 2 | 1 | 2 | 3 | 5 | 5 |
| Sufficient | 2 | 2 | 2 | 2 | 2 | 3 | 2 |
| Understandable | 3 | 2 | 3 | 2 | 3 | 5 | 2 |
| | | | | | | | |
| Total Points | 19 | 21 | 23 | 24 | 19 | 26 | 22 |
| Overall Rank | 1 | 2 | 4 | 5 | 1 | 6 | 3 |

* UOF using separable costs
**UOF using specific costs

| Ranking System |
|---|
| 1=excellent |
| 2=very good |
| 3=good |
| 4=fair |
| 5=poor |

## Appendix 1: Game Theoretical Introduction and Terms

### Introduction

The theory of games is a theory of decision-making.[i] Game theory was created as a tool to mathematically model complex situations, or games. Typically games model situations where one or more parties (players) have conflicting interests. Examples of players are wide-ranging: everything from political parties, governments, and businesses to prison inmates and professional sports franchises. The goal of a game theorist is to predict the decisions and outcomes of the "players" of a "game". Game theory is not used to predict "winners" and "losers". The aim is not to tell you how to play the game, but to tell you certain properties involved with different ways of playing the game that might prove valuable[ii].

Game theory is rooted in mathematics. As such, it can at times be complex and tedious in both its descriptions and applications. The real value of game theory, however, is not in the application of numbers to formulas, but in the critical thinking and deduction used in the analysis of a given game. The context of this paper will be non-technical. The goal here will be to introduce game theory without getting bogged down in all of the math involved.

### History

Game theory was created as a tool to mathematically model complex situations, or games. In 1944, *The Theory of Games and Economic Behavior* by John von Neumann (a mathematician) and Oskar Morgenstern (an economist) was published. Although some of the basic ideas behind 2-person game theory were discussed and published earlier, this book is widely regarded as *the* seminal work in game theory. This book was also the first to introduce n-person games and develop solutions for them. Game theory has since grown from its inception in math and economics and has spread to the fields of political science, psychology, sociology, and biology. In 1994, the Nobel Prize in economics went to the game theorists John C. Harsanyi, John F. Nash, and Reinhard Selten.

### Definitions

Typically games model situations where one or more parties (players) have conflicting interests. The goal of a game theorist is to predict the decisions and outcomes of the "players" of a "game". A **coalition** describes a joining together of different players in a game to act as one. N-person games are analyzed using **characteristic function form**. "The characteristic function of an n-person game assigns each subset S of the players the maximum value v(S) that coalition S can guarantee itself by coordinating the strategies of its members, no matter what the other players do."[iii] In other words, each coalition (S) is assigned a number V(S), which describes the value, or minimum pay-off, that a coalition can expect to get by joining together as a team.

An **imputation** is a reasonable way of dividing the pay-off among the individual players who join a coalition. There is not just one imputation that "solves" the game. There are multiple possible imputations that are **individually rational**[iv]. That is, each player will obtain a pay-off at least as high from joining the coalition as she would from remaining alone. An imputation is **coalitionally rational** if all of the members of the coalition receive a pay-off at least as great as their individual value[v]. These coalitionally rational imputations make up what is called the **core**. Games without a core are unstable, because there is always an individual or a coalition that has more to gain by going it alone than by joining the **grand coalition**, where all of the players in the game join together.

**Example: The Prisoner's Dilemma**

Game theory can be useful in a variety of games, from the very simple to the most complex. There are two basic types of games: 2-person games and n-person games. 2-person games are more simplistic, because they apply to situations with only two players. N-person games are more complex, but they better model realistic situations with multiple players. It will be helpful to briefly introduce 2-person game theory, but 2-person games won't be stressed in this paper.

Probably the most well known example of a strategic 2-person game is the prisoner's dilemma. Because it is simple to understand and so famous, it would be remiss not to mention it here. Two suspects in a major crime are caught and brought in for questioning. They are placed in separate interrogation rooms. There is enough evidence to convict both of them on a minor offense, but without a confession from one or both of them there is not enough evidence to convict either of them of the major crime. If both of the suspects keep quiet, they will be convicted of the minor offense and each will spend one year in jail. If one of the suspects keeps quiet, but the other one "finks" on his partner, then the suspect who kept quiet will get five years in prison, while the informant (the one who "finked") will go free with no jail time. If both suspects fink on each other, then they each get four years in prison. What will they do?

Obviously, there are benefits to both suspects from cooperation and keeping quiet. Each suspect would prefer that they both keep quiet (one year of jail) to both finking (four years of jail). What happens is just the opposite. Both suspects will fink. The dilemma is that the two subjects are in separate rooms, and therefore neither suspect knows what decision the other will make. Each suspect must analyze the situation and make a decision that will benefit himself the most, (or in this case, hurt himself the least) based on what he thinks the other suspect will do. For example, let's say you are a suspect. No matter what you predict the other suspect will do, it is always in your best interest to fink. If the other suspect is quiet, then it benefits you to fink, because then you go free instead of spending a year in jail. If the other suspect finks, then you should also fink, because four years in jail is better than five.

An example of the prisoner's dilemma for n-person game theory is the "tragedy of the commons." Say you are a farmer who shares ground water with multiple other farmers. It would be in all of the farmers' best interests to agree to conserve the water and only use it at a sustainable rate. The problem arises when either there is no agreement or one of the farmers breaks the agreement. As soon as other farmers aren't conserving the water, then it doesn't make sense for you to conserve it either. The water will be all gone soon whether you conserve or not, so you might as well get as much as possible while you still can.

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[i] Davis, Morton. *Game Theory: A Nontechnical Introduction*, p 3. New York: Basic Books, 1983.
[ii] Thomas, L.C. *Games, Theory, and Applications*, p 17. New York: Halsted Press, 1984.
[iii] Thomas, L.C. *Games, Theory, and Applications*, p 86. New York: Halsted Press, 1984.
[iv] Davis, Morton. *Game Theory: A Nontechnical Introduction*, p 184. New York: Basic Books, 1983.
[v] Davis, Morton. *Game Theory: A Nontechnical Introduction*, p 184. New York: Basic Books, 1983.