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Quantifying Equity with Messrs. Markov, Lorenz and Gini: Retaining and Distributing Benefits in Natural Resource-dependent Communities

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Abstract

In this paper, a modified version of the Gini coefficient and social network-based Markov chains are combined to quantify the distribution of benefits in natural resource-dependent communities. This distribution includes both the width and the depth of the circulation of economic benefits from resource extraction. The modified Gini coefficient is used to calculate the share of benefits each party receives (width) while the social network analysis-based Markov chains are used to map the local economy and calculate the average number of times a dollar circulates in that economy (depth). These two values are combined to create an "equity" factor that considers localization and other financial benefits to the community. This combination allows resource managers to optimize resource access based on quantified values other than highest bid/lowest cost.

Keywords: equity, community, management, resources, benefits

1.0 Introduction – Community-based Natural Resource Management

Human survival depends on the extraction of natural resources from the planet. These natural resources may be renewable organic material, such as trees, or non-renewable inorganic material, such as iron ore. Extraction is by necessity mildly disturbing to severely destructive of the environment surrounding the natural resource. While the extraction and processing of natural resources yields economic and social benefits to humans, this must be balanced against the environmental and social costs. There are pertinent questions about to whom the benefits accrue and to whom (and to what) are costs incurred.

Management of natural resources has evolved from highly localized agrarian and maritime societies to larger kingdoms to transnational corporations ostensibly answerable to the governments of the countries within which they operate. The decision-making processes for such global entities have vastly different criteria for

measuring benefits and costs than do the people residing next to the natural resource being exploited. In some locations local residents have retained control over common pool resources such as grazing lands, forestry, and fisheries.

These common areas in which multiple parties can access are often managed through "collective action." The local residents form the governance structure that limits access to the natural resource, through the development of rules that establish who can access the resource and how much they can extract. A substantial amount of effort has been devoted to understanding the causes of successful and unsuccessful collective management of natural resources. Elinor Ostrom has focused on the design and "rules in use" aspects of the institution managing the natural resource, and has identified several components that are consistently present in successful collective action institutions (Ostrom, 1990, 1992, 2005). Evelyn Pinkerton has focused on "co-management" arrangements between local communities and larger government bodies, and identified several rights that were devolved to the local management body in successful cases (Pinkerton & Weinstein, 1995; Pinkerton, 1999; Pinkerton & Silver, 2011).

The concept of social equity in community-based management of natural resources contains norms about the distribution of economic benefits within that community. An imbalance in the distribution of benefits can lead to a relatively few achieving greater rewards than the balance of the community members, which can lead to a loss of social capital and trust, and can be a significant component of the unsustainable management of the resource (Andersson & Agrawal, 2011). Critical analysis of community-based management regularly identifies inequities in benefits and power imbalances as considerable factors in outcomes of proposed decentralization programs, once actually implemented. Leach et al. (1999) suggest that community members' perception of the "collective good" is based on the members' social position. Gibson and Lehoucq (2003) correlate sustainable local management with political expediency for local politicians. Others note that democratic management locally does not spontaneously appear upon the decentralization of resource management (Platteau & Gaspart, 2003; Bradshaw, 2003; Ribot, 2004), leading some researchers to examine the impact of "local tyrannies" (see Andersson & Ostrom, 2008 for an overview). If the priorities of the powerful in the community do not include a genuine desire to sustain the local resource base, then we should not expect the outcomes to differ from those of centralized management (Bradshaw, 2003, p.5).

Equity and equality are related but not the same, in that a certain degree of equality (sharing) is necessary to achieve equity (fairness). Equitable distribution is not simply having economic benefits retained by a local economy, or "spreading" the benefits around. Equitable distribution contains both equally, as two aspects independent of each other yet intertwined, much like two dimensions describing a rectangle. The "wideness" of the distribution of benefits is as important as is the "depth" of the penetration of the benefit into the local economy. This paper endeavors to develop a method to quantify the equitable distribution of benefits in natural resource-dependent communities, using social network analysis, Markov chains, and the Gini coefficient.

2.0 Developing the Measurement Tools

2.1 Social Network Analysis, Input-output Models, and Markov Chains

Social network analysis (SNA) is a useful tool for analyzing community relationships (Knoke & Yang, 2008), and is experiencing a high level of interest in analyzing community-based management, as a method to analyze power relations and clustering (e.g., Ramirez-Sanchez & Pinkerton, 2009; Lauber et al. 2008).

There are several software packages that can take SNA data and render graphs and calculate metrics such as "betweenness-" and "closeness-centrality". Gephi (<http://www.gephi.org>) is one such application and is a Java-based application that runs on all computer platforms with a Java engine.

SNA data is built from identifying relationships between any two entities, known as "nodes," within a system, such as a community. Connections between nodes can be directed (one way) or undirected (both ways), and are also known as "edges." An example of an undirected connection might be members of a hiking group in a community, while an instructor or trail guide could have a directed connection to the people in the group. The connection strength may be a 0 (no connection) or 1 (connection), representing a binary relationship, or may range in values across any arbitrary scale (Hanneman & Riddle, 2005; Knocke & Yang, 2008; Wasserman & Faust, 1994). The "adjacency matrix" form of SNA represents nodes as rows in a matrix, and the connections to other nodes are listed in the columns of each row, with each column representing the nodes in the system (Hanneman & Riddle, 2005, Chapter 5).

The economic input-output model was developed in the "late 1930s" by Wassily Leontief, as a method of calculating the required output necessary by upstream industries to meet input needs of downstream industries as those downstream industries' output changes (Miller & Blair 2009, p. 1). These demand requirements can be written as linear equations, representing the total demand for a given industry, and these linear equations can be expressed in matrix form. One form of a "multiplier effect" can be calculated from input-output models, using the "Leontief inverse" (Miller & Blair, 2009, p. 21). This form of the multiplier effect is the direct, indirect and induced increases in economic output necessary to support a given increase in output by a specific industry. For example, if labor is one of these industries, the increased number of jobs can be calculated. Some of these jobs will directly come from the industry; some jobs will be indirectly created from industries that produce products used as raw materials (inputs) for the industry that is increasing its output; and some jobs will be "induced" through increases in these supplier industries.

Markov chains are based on the 1907 work of A. A. Markov, who studied probability of transitions between multiple states (Grinstead & Snell, 1997, p. 405). These transitions can be sequential, leading to the concept of "chains." For example, an object may go from state A to state B to state C, or it may go from state A to state D. The probability of finding the object in state A, B, C, or D at any given point in time is the focus of Markov chain mathematics. The probabilities can be written in matrix form, known as a transition matrix. If a state cannot be left once arrived at (the probability of transitioning to another state is 0), the Markov chain is defined to be an "absorbing" Markov chain (Grinstead & Snell 1997, p. 416). The average number of transitions (also known as the average path length) from any state to an absorbing state and the number of times other states will be entered before reaching an absorbing state can be calculated, using the "fundamental matrix" (Grinstead & Snell, 1997, p. 418). An example of Markov chains is the game of Snakes and Ladders (also known as Chutes and Ladders). For any given configuration of the game, the average number of turns before the game is completed is found by calculating the probabilities of landing at any square until exiting (Althoen et al., 1993). Markov chains have been applied to a wide range of subjects, including queuing theory, ecological food webs, genetics, games, and information theory. For this article, the economy of a community is equivalent to the game of Snakes and Ladders, with a dollar equivalent to a player's piece as it travels through the game.

All three tools above are functionally identical in normalized matrix form (see the companion article by the authors, "Social network analysis, Markov chains and input-output models: Combining tools to map and measure the circulation of

currency in small economies," in this issue of JRCD, for a rigorous treatment of this). Since the average path length and the Leontief inverse are constructed and calculated in identical ways, and the Leontief inverse is a widely-accepted method for calculating the multiplier effect, the conclusion is that the average path length for a dollar entering a community until it exits is the same as the multiplier effect, on a more granular scale. Furthermore, social network analysis tools can be used to construct the map of the community's economy and the data from the map can be analyzed with Markov chains to determine the average path length (multiplier) for that community.

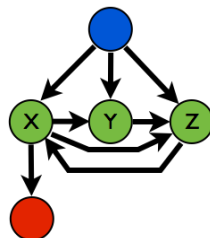
2.2 Mapping

The equivalence of these three tools allows the construction of a map of paths that a dollar may take from the point it enters the community to the point it exits. For the purpose of mapping, the points of entry and exit can be represented by single nodes. Businesses and individuals are represented as nodes. The "bond" (edge) between nodes is the exchange of currency between two entities, with the direction of the edge going from buyer to seller. In order to utilize Markov chains, the exchange is in terms of the percentages of expenses going from a business to other businesses in the community. It is not necessary to know the actual dollar amounts each business receives as income, as this can be modeled. The percentage of expense represents the probability of a dollar going to that downstream business.

Following the matrix form for social network analysis, the percentages will be in rows, with entry into the community in row 1, with business X's expense distributions in row 2, business Y in row 3, etc. Each column represents a downstream business, with column 1 occupied by entry into the community from outside (as a single node). Column 2 is business X, column 3 is business Y, etc. The last row and column represent exit from the community. For example, Eqn. 2.2.1 shows an expense matrix. Twenty percent of the total dollar amounts entering the community go to Business X, 50% go to Business Y, and 30% go to Business Z. Business X spends 35% of its expenses with Business Y, 45% with Business Z, and 20% outside of the local economy. All (100%) of Business Y's expenses are with Business Z, who in turn has all of its expenses with Business X. The astute reader will note this forms a loop. As all expenses going to the node marked "exit" remain with that node, "exit" is an "absorbing state," as per Markov chain definitions.

$$2.2.1 \quad A = \begin{matrix} & \begin{matrix} enter & Bus.X & Bus.Y & Bus.Z & exit \end{matrix} \\ \begin{matrix} enter \\ Bus.X \\ Bus.Y \\ Bus.Z \\ exit \end{matrix} & \begin{pmatrix} 0 & 0.2 & 0.5 & 0.3 & 0 \\ 0 & 0 & 0.35 & 0.45 & 0.2 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \end{matrix}$$

Figure 2.2.1: Map of matrix in Eqn. 2.2.1.



Readers familiar with social network analysis adjacency matrices should recognize the form above. As the rows are all normalized (sum to 1), the matrix is also in canonical form for Markov chains. The average path length (multiplier) is determined from calculating the fundamental matrix using the above transition matrix and the identity matrix (a matrix with 1s on the diagonal and 0s elsewhere). Social network analysis software tends to focus on the shortest path length between two nodes (the "geodesic"), without considering the average path length from one node to another. Inclusion of this metric would be a convenient addition to any SNA package. Many packages include a calculation of the "average path length," but this is the average of the shortest paths between all nodes in the system, which is not the same.

Once in transition matrix form, the average path length is calculated by solving the inverse of the identity matrix minus the transition matrix (resulting in the "fundamental matrix"). Microsoft Excel and the Open Office Calc spreadsheet applications can calculate the inverses of matrices, and the values for the accompanying case study use this method. Alternatively this can be calculated using the "Gauss-Jordan Elimination method" through a programming language such as PHP or C (see Kelly, 2012 for a rigorous examination).

2.3 Mapping Loops and Calculating their Impacts

An example of mapping showing a small loop will be shown.

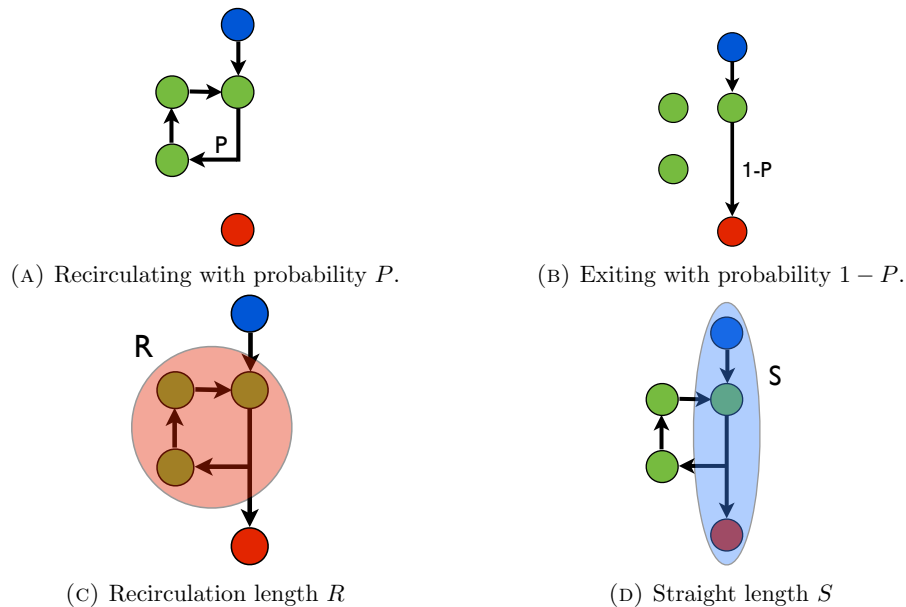
Figure 2.3.1a: Five nodes in a chain. Figure 2.3.1b: Five nodes with a loop.



Consider two economic chains, with an equal number of businesses (see Figures 2.3.1a and 2.3.1b). The blue circle represents currency entering the community and the red circle represents it leaving. For the chain represented in Figure 2.3.1a, assuming each business spends 100% of its expenses with the next business in the chain, the total economic activity is the sum of the transactions. If each transaction is \$100, and each arrow represents a transaction, the total economic activity is \$400 (dollars flow in the direction of the arrows, products and services flow in the opposite direction).

For the chain represented in Figure 2.3.1b, the situation is different. Let P be the probability that the dollar will circulate through the loop (see (A) Figure 2.2.2), while $1-P$ is the probability the dollar will escape (see (B) Figure 2.2.2). Let R be the length around the loop of green circles (See (C) in Figure 2.2.2, R is equal to 3), and let S be the length from the blue circle to the red circle (see (D) in Figure 2.2.2, S is equal to 2). The path length \bar{L} is the average number of transactions a dollar experiences before escaping to the red circle.

Figure 2.3.2: Components of a simple five node loop.



If the percentage of recirculation is 50%, half of the dollars escape during each period of time, but half recirculate. Although the economic impact of this recirculation diminishes as half escapes each loop, the contribution to the economic activity remains for many loops.

The companion article by the authors, "Social network analysis, Markov chains and input-output models: Combining tools to map and measure the circulation of currency in small economies," in this issue of JRCDD, discusses the solution to this looping, and derives the formula:

$$(2.3.1) \quad \bar{L} = \left(\frac{P}{1 - P}\right) \cdot R + S$$

The average path length in the above five-node loop is the ratio of the probability the dollar will recirculate to the probability it escapes, multiplied by the length of the loop, plus the length of the straight route. Using the formula calculated above (Eqn. 2.3.1), the impact of recirculating dollars can be quantified. There are three nodes in the loop R , and the length S is two (from blue to green to red). For a probability of recirculation P of .5, the average path length (multiplier) is 5:

$$(2.3.2) \quad \bar{L} = \frac{.5}{1 - .5} \cdot 3 + 2 = \frac{.5}{.5} \cdot 3 + 2 = 5$$

In the original chain (Figure 2.3.1a), the income was \$100 and total economic activity was \$400. With the same number of businesses and a loop recirculating 50% of the income going to the first business, the total economic activity is 5 times the input, or $\$100 \cdot 5 = \500 . Alternatively, if the initial transaction is \$80, the total economic activity in the economy recirculating 50% is \$400 - the same as the total economic activity in Figure 2.3.1a, but with a lower input. The ability to maintain the same level of economic activity in spite of a lower input means greater community economic resilience in the face of decreased global economic activity. Additionally, it means the same amount of economic activity while requiring less raw materials.

Although the total economic activity of a loop requires a longer time period to achieve, this economic activity persists in the absence of continuing inputs from outside the community. Because of this, communities dependent on natural resource extraction should undertake building loops within the community as a mitigation effort against the frequent boom and bust cycles prevalent in global and regional natural resource commodity markets (Pinkerton & Benner, 2013; Clapp, 1998). A real-world example of a loop in a local community, as revealed by a survey conducted by the primary author (unpublished): A mill in a small community in British Columbia received an order for some wood products, and hired a logger to obtain the trees. The logger paid the local community forest for the trees and delivered them to the mill. The community forest paid an annual benefit to the municipality that had the tenure rights for the community forest. The municipality hired a contractor to repair some sidewalks, using the benefits from the community forest. The contractor also built custom log homes and hired a different logger to obtain wood for a client. The logger harvested the logs from the community forest. (Due to invoked confidentiality agreements by the aforementioned community forest, the community forest cannot be named.)

3. Equity

3.1 Equity in Community-based Resource Management

While substantial literature has been devoted to the successes of community-based natural resource management, some critical analysis of community-based natural resource management shows failures do occur, in sufficient numbers that some authors have expressed concern about the quality of research by those espousing successes (see e.g., Bradshaw, 2003, Castree, 2011). Failures may occur for a variety of reasons, and certainly how the benefits of local management are distributed is one factor. To repeat an earlier statement, an imbalance in the distribution of benefits leads to relatively few achieving greater rewards than the balance of the community members, which can lead to a loss of social capital and trust, and can be a significant component to the unsustainable management of the resource (Andersson & Agrawal, 2011). Therefore, the distribution of benefits and the equity of that distribution should be examined when analyzing success or failure of community-based management of natural resources.

The issue of equity is of such importance that Nobel Prize-winning scholar Dr. Elinor Ostrom included it as a design principle, making equivalence between reward and effort one of the key characteristics present in long-term sustainable community-based management (Ostrom, 1992, p. 69; 2010). Pinkerton and Weinstein (1995) identify the right to allocate internally, using community norms or rules, as necessary for successful community-based management of fisheries, and discuss how the case-study community would practice equitable "resource access or distribution." McDermott (2009, p. 250) builds a framework around equity in analyzing community-based forestry (CBF), positing that "CBF initiatives will bring about social change when they transform the distribution of access to resources and decision-making power and scope." (McDermott 2009, p. 250) further observes that "In order to reduce inequity, community-based organizations must make social equity an explicit target to which they hold themselves accountable."

Equity issues appear in many case studies on community-based management. Sebele (2010) documents challenges to sustainably maintaining a community-based tourism destination in Botswana, as the community members feel the local elite use the Khama Rhino Sanctuary as their personal park. Iversen et al. (2006) document elite capture of forest user groups in Nepal, leading to structural instability. Other cases studies document the capture of community-based natural

resource management by local elites, such as the forests in Cameroon (Brown & Lassioe, 2010), communal farming in South Africa (Lebert & Rohde, 2007), and agricultural land management in Australia (Pero & Smith, 2008). Capture of community-based management by local elites is far from the exception (Platteau & Gaspart, 2003; Bardhan, 2002). Often, though, this is not documented by researchers, perhaps due to pressure to publish only positive results (Mansuri & Rao, 2004).

Equity and equality are related but not the same. Equality suggests the same share, while equity is concerned about the fair share. Baland and Platteau (1999) and Pérez-Cirera and Lovett (2006) both cite Mansur Olson's *The Logic of Collective Action: Public goods and the theory of groups* (1965) as a counter theory to suggestions that community-based management must distribute benefits equally (as opposed to equitably). According to the authors, Olson suggests that minor inequality increases incentives for powerful interests to discourage free-riding by those who would gain less by contributing, while major inequality works against collective outcomes. Dasgupta and Beard (2007, p. 229) offer support for this conjecture in community-driven economic development programs in Indonesia, where they state that "(i)n cases where the project was controlled by elites, benefits continued to be delivered to the poor, and where power was the most evenly distributed, resource allocation to the poor was restricted."

As a means of quantifying the level of equality, as a component of equity, this paper suggests using the Lorenz Curve and the Gini coefficient, two analytical methods for evaluating the distribution of an attribute among a population.

3.2 Lorenz Curves

The "Lorenz curve" is named after Max O. Lorenz, who developed a method to graphically represent the concentration of wealth within a population (Lorenz, 1905). This method orders equal-sized segments by the amount of wealth each segment has, such that a cumulative total is obtained with the addition of each segment. For example, populations are often segmented by quintiles (fifths). A hypothetical five segments might have the following percentages of the total wealth: 4%, 10%, 15%, 21%, and 50% (i.e., the bottom 20% of the population has 4% of the total wealth, while the top 20% has 50% of the total wealth). This is a deviation from a uniform distribution in which each quintile has 20% of the wealth. The two lowest segments cumulatively account for 14% of the wealth (4%+10%), and the four lowest segments cumulatively account for 50% of the wealth (4%+10%+15%+20%). Figure 3.2.1 shows the curve (in red) generated by plotting these points. The Lorenz Curve is the curve formed by the hypothetical distribution posited above. The sharp uptick occurs after 80% of the population is accounted for, but only 50% of the wealth is, and the last 20% of the cumulative population accounts for the remaining 50%. Additionally, the "Line of Perfect Equality" (in green) is formed by the uniform distribution.

A common measure of inequality is to examine the area between the Line of Perfect Equality and the Lorenz curve (Area A in Figure 3.2.2, representing the deviation from equality), and take its ratio to the total overall area (Areas A+B in Figure 3.2.2). This ratio is known as the Gini coefficient (Sen & Foster, 1997, p. 30). Gini coefficients range from 0 (no deviation from equality) to 1 (complete deviation from equality).

Figure 3.2.1: Lorenz Curve.

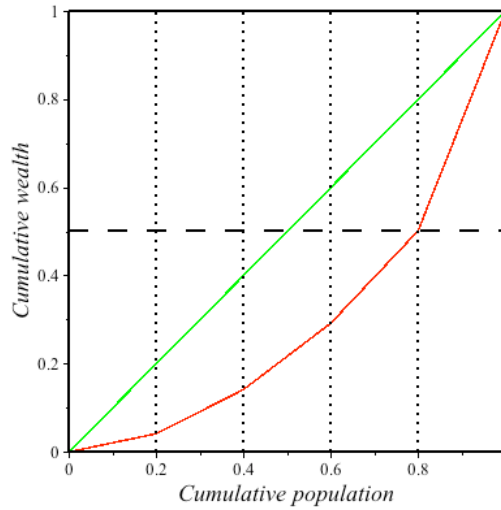
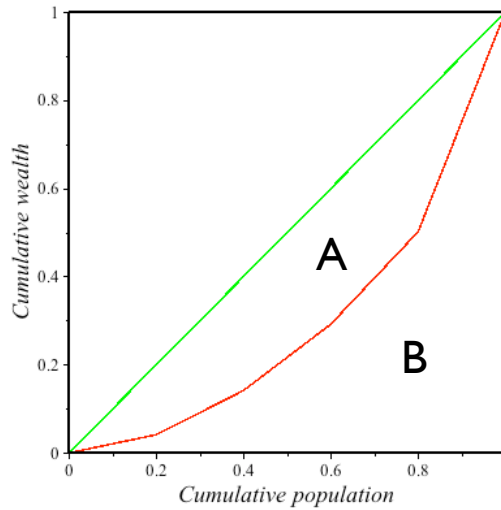


Figure 3.2.2: Gini Coefficient from Lorenz Curve.



$$G = \frac{A}{A + B}$$

The Gini coefficient can be directly calculated, as is primarily done when the data is directly available (Eqn 3.2.1).

$$(3.2.1) \quad G = \frac{\sum_{i=1}^n \sum_{j=1}^n |x_i - x_j|}{2n^2\mu}$$

Of note is that Eqn. 3.2.1 represents the maximum possible value for the Gini coefficient in a group (it can be shown to reduce to $G = (n-1)/n$ in cases of perfectly unequal distribution). In a simple case such as $n = 2$, all of the resource going to one of the two individuals yields a Gini coefficient of 0.5, even though there is perfect inequality in distribution. As such, Gini coefficients approaching 1 can only be achieved with large numbers in a set with a high degree of concentration among only a few members. To remove bias from the set, the Gini coefficient must be multiplied by the correction factor $n/(n-1)$ for small sets. As a guideline, Dixon, et al., (1987) suggest

using the corrective factor where n is less than 100, which will be the case with small economies.

3.3 *Positivist vs. Normative*

Conceptually, the area denoted by A can be thought of as the "Area of Inequality," as it is the deviation from perfect equality. Conversely, the area denoted by B can be thought of as the "Area of Equality." For purposes of including equality in managing natural resources, area A is a positivist quantification of how things are, while area B is a normative quantification of how things could be (suggesting area B should be increased). The ratio of the Area of Equality to the total area is equal to 1 minus the Gini coefficient:

$$(3.3.1) \quad 1 - G = \frac{B}{A + B}$$

As the Gini coefficient can be calculated, $1-G$ can be as well, to create a normative "equality Gini coefficient (eGC)":

$$(3.3.2) \quad E = 1 - G$$

The normative encouragement of this approach is reinforced by the recognition that while G goes to 0 as equality increases, $1-G$ goes to 1 under the same conditions (an increasing value as more benefits are distributed locally). These are effectively interchangeable values, depending on whether the focus should be on the inequality of a situation or the equality of it. As will be shown later, using the normative "equality Gini coefficient (eGC)" has additional value when measuring equity performance of businesses.

3.4 *Applications of the Gini Coefficient*

The most common usage of the Gini coefficient is in economics, to measure income inequality. One example is that of Canadian income and wealth distribution, in comparison to the United States of America (USA). Canada's pre-tax income distribution in 2005 was 0.32, while the USA was .45 in 2007 (CIA, n.d.). Canada's net worth Gini coefficient was .659 in 2005 (Brzozowski, et al., 2010), whereas it was .77 in 2006 in the USA (Heathcote et al., 2010). Conceptually this equates to the top 20% controlling 63.1% of the wealth in Canada (Davies, et al., 2011) and 84% of the total wealth in the USA (Ariely & Norton, 2011). In both countries, the bottom 20% have a negative net worth (Davies, et al., 2011). An example of group averaging creating an artificially lower Gini coefficient is that while 84% of the total wealth in the USA is owned by the top 20% of the population, estimates put 57.7% of the total wealth in the hands of only 5% of the population, with 32.7% in the top 1% (Davies et al., 2011). Averaging the top 5% and 1% within the top 20% masks the true level of concentration and lowers the Gini coefficient.

An advantage of using the Gini coefficient for comparisons is that it is independent of the scale of the attribute being measured. While the USA, Iran and Mozambique have substantially different economies in terms of size and GDP, they can be compared against each other in terms of income inequality (all three have pre-tax income Gini coefficients of .45 (CIA, n.d.)).

Wilkinson and Pickett (2009) took this approach and analyzed the outcomes of a large number of social ills across many countries, in their book *The Spirit Level: Why Equality is Better for Everyone*. With only the occasional exception, Wilkinson and

Pickett found a strong correlation between inequality within a country and unfavorable outcomes for social ills such as teen pregnancy, alcoholism, crime and incarceration rates, and obesity. Taking this approach to the community level, Modrek and Ahern (2011) apply the Gini coefficient to "cantons" in highly homogenous Costa Rica and find some support for decreased health within communities with unequal wealth and income distributions. Some factors that could not be controlled for included migration within the country and the long period before onset of diseases associated with inequality. Nonetheless, Modrek and Ahern concluded that inequality at a local level is likely to contribute to less favorable health outcomes.

Chakraborty (2001) uses the Gini coefficient to characterize the land distribution in Nepal while analyzing the outcomes of common pool forestry management institutions, and identifies these management institutions as responsible for the distribution of access to forest products. Chakraborty identifies issues with inter- and intra-group inequities in access and distribution of benefits as challenges to sustainable management of the forest commons, but does not apply the Gini coefficient to that distribution. Fum and Hodler (2010) find income inequality among natural resource rich countries increases with a few large "polarized" ethnic groups, but decreases in countries with many small ethnic groups. To this end, Pérez-Cirera and Lovett (2006) construct a model using Gini to inform government authorities as to which community forests (ejidos) need greater oversight due to power imbalances.

Lerman and Yitzhaki (1985) developed a method for determining which component contributes the most to inequality, in cases where there are multiple income sources, and decomposition is possible. This is used by Babulo et al. (2009) to isolate forest products as contributions to income in rural Tigray, Ethiopia, and finds that access to forest products reduces poverty and inequality, and should be incorporated into forest management plans. Similarly, Mamo et al., (2007), in studying income inequality in Dendi, Ethiopia, constructed two Gini coefficients, one including forest products-dependent income and one not, to isolate the contributions from access to forest products. They also found a reduction in income inequality from access to forest products. Kant et al., (1996) are even more granular, looking only at non-timber forest products, and conclude the same, that inclusion of these products decreases income inequality.

Outcomes of government policies can be quantified using the Gini coefficient. Lee (2009) examined income in tourism services-dependent communities in the U.S. and found that income inequality increased in all of them between 1990 and 2000. The highest increase in inequality came from mountain ski resorts, mirroring the ongoing challenges in Whistler, B.C., where services employees have difficulties finding affordable housing in Whistler (Gill & Williams, 2011). The "hypothetical" distribution used to create Figure 3.2.1, where the top 20% own 50% of the wealth, came from Lee (2009), as the wealth distribution in a typical mountain ski resort county. In contrast, Lee found counties with national parks had the least increase in inequality, and counties dependent on manufacturing had no changes in inequality. These findings highlight the need to examine the distributions of benefits in efforts to attract tourism to communities.

The reader should note that (a) although lengthy, the above is not a comprehensive literature review of the use of the Gini coefficient and (b) the articles above connect to many issues identified within community-based management of natural resources and should serve as a clear statement that at least some aspects of these issues can be quantified and measured.

3.5 Identified Gap: Distributing Benefits Using the Gini Coefficient as a Policy Guideline

While there is a wide range of literature that includes the use of the Gini coefficient as a measurement of the distribution after the distribution has occurred, there appears to be a shortage of literature discussing using the Gini coefficient in advance of the distribution. The authors of this paper have been unable to locate any case studies in which a community-based management institution used the Gini coefficient as a guideline for distributing benefits. This paper will now develop a method for applying the equality Gini coefficient (eGC) to the distribution of benefits, in conjunction with the average path length per vendor developed earlier, to provide a quantifiable approach to distributing benefits from community-based management of a natural resource. This is done through balancing the average path length of resource consumers with a distribution that is at least as equal as that given by a particular Gini coefficient. As will be shown, it is not possible to simultaneously maximize both the average circulation of currency and the distribution of benefits. Rather, an optimal trade-off must be found.

Benefits may range from harvesting and extraction opportunities to the disbursement of funds through grants to community groups. As noted by Pinkerton, et al. (2008), access to the timber by local mills is a benefit of community-based management of forests. For this example, in using the eGC as a policy guideline, a hypothetical community with local supply chains will be used. These supply chains begin with businesses that purchase timber from a community forest, and who then sell it to a local mill. These local mills may sell the wood to local value-added manufacturers, which may then sell to retailers. The specifics of the supply chain will not be documented, and the example supply chains will be simplified and exaggerated, by considering only sequential transactions and by positing unrealistically high lengths, for purposes of illustration. Earlier, we explained how this supply chain represents the average path length of currency from the time it enters a community to the time it leaves. The resource itself flows in the opposite direction from the currency.

The supply chain also represents effort towards improving the community's capture of benefits from the natural resource, which is a component of one of Ostrom's design principles, that of proportional equivalence between benefits and costs (Ostrom, 1992). Conceivably a business, as well as other components on the supply chain, has to make concessions towards sharing costs in order to achieve long supply chains locally. Reasonably, then, these longer supply chains can expect to receive a greater proportion of the benefits from the natural resource. At the other end of the spectrum, the business with the shortest average path length benefits the community the least, and should expect to receive the smallest share.

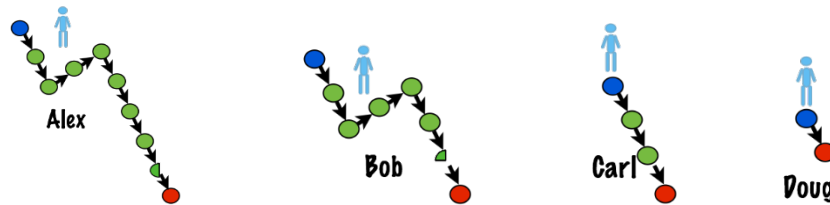
For this example, four average path lengths will be used: 8.53, 5.23, 2.98, and 1.0, from businesses owned by Alexandra, Bob, Carl and Doug, respectively (See Figure 3.5.1). For illustrative purposes, assume that these businesses are the only businesses in the supply chain that can utilize timber directly purchased from the community forest. The first (Alexandra) represents a value-added business who has achieved complete processing of the timber locally (utilizing loggers, truckers, scalers, mills, and other businesses), while the last (Doug) represents a timber buyer who is from out-of-town and uses non-local labor while selling the timber out-of-town as well. Conceivably this timber buyer also offers the highest price for the timber, or some other incentive as a reason to be included in the distribution of access to the timber.

The companion article by the authors, "Social network analysis, Markov chains and input-output models: Combining tools to map and measure the circulation of

currency in small economies," in this issue of JRCD, explores how community forests can lower timber access costs to local businesses while maintaining the same gross economic activity. Community forests have to balance the potentially higher costs of purchasing locally against the lower revenue of selling locally at a reduced price. Both work to reduce the net income of the community forest, which may impact its ability to distribute grants to local social-responsibility groups. Community forests may find it quite rational to maximize the local collective outcomes through partnerships instead of its own individual outcome in isolation.

For this example, the last node in the chain represents the community forest, as it pays the province for the removal of timber from Crown lands. Goods and services move in the opposite direction as currency (the flow of which is represented by the arrows). The sale is to the first node upstream of the community forest, but conditional on the contracts in place for the processing. Fractional chain lengths occur because not all of the businesses along the chain have 100% of their income and expenses in line with the chain; therefore, they may not contribute a complete node to the chain. While exaggerated, the premise of this example is not unrealistic; see Pinkerton and Benner (2013) for a comparison of resilience of small value-added enterprises against commodity mills in the Columbia-Kootenay region of British Columbia. In a real-world system, the community forest would be a node in the middle of a chain, with goods and services purchased and benefits distributed downstream and access to raw materials sold upstream.

Figure 3.5.1: Graphic depiction of business path lengths.



If the community chooses to maximize local economic activity, all of the timber would go to Alexandra, who has the longest local supply chain. Using Eqn. (3.2.1), the Gini coefficient of this arrangement is 0.75, the maximum possible Gini coefficient for this number of members in a set:

$$(3.5.1) \quad G = \frac{n-1}{n} = \frac{4-1}{4} = \frac{3}{4} = 0.75$$

Corrected for bias (multiplying by $n/(n-1)$, or $4/3$), this Gini coefficient is 1.0. Using the eGC discussed above, this scores a 0 ($1 - G = 1 - 1 = 0$), as in zero equality. If the community chooses to maximize income received from sales of the timber, all of the timber would go to Doug, who offers the highest price, but again this has an equality Gini coefficient of 0. If the community chooses to maximize the distribution of access to the timber, the Gini coefficient is 0.0 (no differences in pairs, so the summations equal 0). Conversely, this is an eGC of 1.0 - a perfect score.

The projected circulation of currency within the logging community is then the weighted average of each business' supply chain. With four businesses and uniform distribution, each business would get 25% of the access, or in this specific type of example, 25% of the total allowable harvesting of timber for a given period. The aggregate average path length (L) is then the sum of 25% of each business' average path length.

$$(3.5.2) \quad L = .25 * 8.53 + .25 * 5.23 + .25 * 2.98 + .25 * 1.0 = 2.13 + 1.3 + .75 + .25 = \mathbf{4.435}$$

This aggregate average path length L of 4.435 is less than the maximum possible of 8.53, obtainable by allocating all of the harvest to Alexandra. Maximizing one variable, such as the distribution of access or the maximum economic activity or return, comes at the expense of the other variables. Therefore, the goal should be to find the optimal balance of variables. For this example, the balance will be between the collective community economic activity and the distribution of access, while leaving out economic return for the community institution managing the resource (basically assuming a fixed price for timber).

As discussed earlier in this paper, small imbalances in power and benefits may be beneficial to community-based management. Attempting to achieve perfect equality in the distribution of benefits may be counterproductive. However, excessive imbalances in power and benefits are likely to lead to conflict and eventually to unsustainable utilization of the natural resource and/or capture of control of the resource. Therefore, in managing the resource, a reasonable goal is to choose a distribution that is reflective of a wider community profile. For example, as noted earlier, the pre-tax income distribution Gini coefficient in Canada is 0.31, or an eGC of 0.69. The following example will use an eGC of 0.65 as a minimum standard of equality in the distribution of benefits.

If Alexandra receives 50% of the allocation, and each of the other three businesses receive 1/3 of the remaining 1/2 of the allocation, the eGC is 0.67 and the aggregate average path length L is 5.8.

$$(3.5.3) \quad L = .5 * 8.53 + .1667 * 5.23 + .1667 * 2.98 + .1667 * 1.0 = \mathbf{5.80}$$

This eGC is above the guideline of 0.65, but already shows a high concentration towards the top 25%. Communities with many businesses may find it easier to obtain high eGC values (indicating a tendency towards equal distribution), but where communities have only a few options, there will be a difficulty in not concentrating timber sales. The burden should then be on the businesses to ensure their returned effort towards the community is proportional to this extra benefit.

Tweaking of the Gini coefficient for a longer average path shows that an eGC of 0.584 (Alexandra receives 50%, Bob receives 25%, and Carl and Doug each receive 12.5%) has an aggregate average path length of 6.07, but is below the minimum allowable eGC. An additional allocation change, where Alexandra receives 47%, Bob receives 23%, Carl receives 17% and Doug receives 13%, yields an eGC of 0.654 and an aggregate average path length of 5.86. This appears to be the optimal balance, and further calculations are unlikely to offer substantial increases in the aggregate average path length. To increase the aggregate average path length, more allocation must be given to Alexandra, but doing so will fail to meet the lower limit of the community's equality Gini coefficient. Other distributions may yield the same Gini coefficient. Attempting to find which distribution has the highest aggregate average path length among identical Gini coefficients would be instructive towards which one to choose. Surprisingly, the initial allocation was close in both Gini coefficient and average path length, although this does not reward Bob and Carl for their longer supply chains.

Table 3.5.1. *Equality and Length Outcomes for Maximal and Optimal Goals*

Goal	GC	Equality GC	L
Maximum Length	1	0	8.53
Maximum Revenue	1	0	1.0
Maximum Distribution	0	1	4.435
Optimal Distribution	0.346	0.654	5.86

3.6 *Gini Coefficients for Individual Businesses*

Equality Gini coefficients for individual business can be calculated by analyzing the distribution of their expenses to local businesses. If all of a business' expenses leave the community, the eGC for that business is 0. If there are 10 businesses in town, and Business A spends 90% outside of the community, but distributes 5%, 2.5%, 1.5% and 1% of its expenses to four local businesses, the corrected eGC for Business A is 0.04. Adding a fifth business that receives 10% of Business A's expenses raises the corrected eGC to 0.08.

Incrementally this change may seem small, but it is a quantifiable difference. Therefore, given two individual businesses with identical average number of transactions (meaning their relative aggregate community-level economic impact is identical), the business with the higher equality Gini coefficient is distributing its expenses more widely. Consistent with Ostrom's principle of proportional benefits and efforts (Ostrom, 1992), the community forest can justifiably offer a lower price to the business that is distributing its expenses more widely than other businesses. Note that the emphasis is on "relative" impact, as this makes no statement about the size of the business in absolute dollars but only in terms of their performance using the dollars they have.

3.7 *Combining Techniques to Evaluate Business Contributions to the Community*

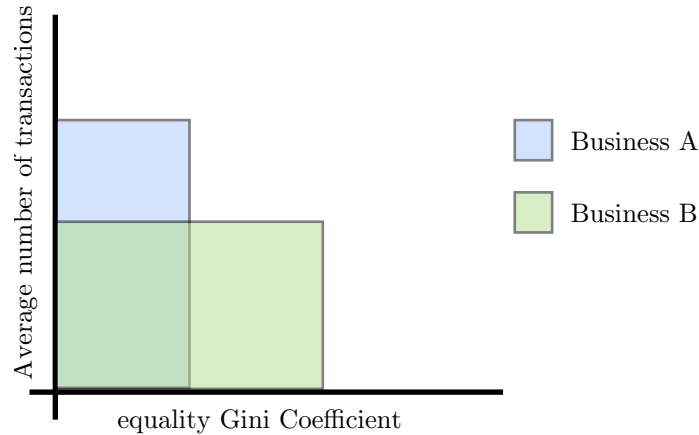
To combine the techniques, the average path length of each business can be multiplied by the equality Gini coefficient for each business. This combined value creates a measure of equity with the relative benefit to the local community on one axis and the spread of that distribution on the other. It is also scale-independent; while there may be businesses that have a larger economic impact in absolute dollars, small businesses may be doing more for the community.

For example, assume Business A has an average number of transactions (multiplier) of 2.0 and a Gini coefficient of 0.95, while Business B has an average number of transactions of 1.25 and a Gini coefficient of 0.90. The aggregate economic impact is greater for Business A, but the impact is distributed more with Business B. This is better illustrated with the modified GC, which gives Business A an eGC of 0.05 and Business B an eGC of 0.10 (for GC, less is better, but for eGC, more is better).

The area of each business' rectangle can be calculated by multiplying the two values (eGC and multiplier) together. As such, Business A has a combined value (area) of 0.10, while Business B has a combined value (area) of 0.12. Figure 3.7.1 depicts the differences, and as calculated above, Business B has a slightly larger area. This is by no means the only method for deciding how to handle this situation, but one that readily suggests itself. Additional quantifiable values could be included for higher-order dimensional shapes.

At the risk of stating the obvious, this technique can also be applied to quantify some of the decision-making during the process of evaluating grants to community groups.

Figure 3.7.1: Comparing two businesses.



4. Conclusion

The issue of capturing benefits from the extraction of natural resources is an extremely important one. The value of the natural resource in raw form is a small fraction of the value in its processed and finished form. The high volume-low profit nature of raw material extraction leaves little chance to capture value, emphasizing the need to circulate the benefits as close to the extraction site as possible. As with anything involving money, this circulation is at risk for capture by local elites, and sustainable management of the natural resource inherently requires equitable distribution.

The use of Markov chains can quantify how well the benefits circulate, while the use of the Gini coefficient can quantify how well the benefits are distributed. Markov chains allow the calculation of an outcome based on probability, and are essential to modeling the probability a dollar will go from one business to another, based on the percentages of expenses for a business. The Gini coefficient is a method for quantifying the distribution of the slices of a pie among the diners. By quantifying this value, the community can set a socially acceptable level of concentration of benefits, ideally in conjunction with the idea of proportionate benefits for the amount of effort put into the resource. Those that put the most into managing the resource can be rewarded by getting the largest proportion of the benefits, within a limit that ensures the benefits are available widely. In the case of Markov chains, the mathematics is identical to social network analysis and input-output models, allowing additional tools to be brought to the analysis of the distribution of benefits.

The actual implementation of these tools faces some practical challenges, however. There are on-the-ground realities to consider, including the lack of industrial and professional capacity in rural natural resource dependent communities. In particularly rural or undeveloped communities, both of these challenges may be present, where businesses have difficulty providing the necessary information because their accounting books are still done with pencil and ledgers, and there is almost no local capacity to do value-adding to the raw timber. These communities' choices may be largely limited to (a) how far they should ship the resource in raw form, and (b) whether or not buyers farther away might pay more than local buyers, such that it offsets the extra delivery costs.

The tools are quantitative, and they do require a different approach to organizing accounting records. With computer-based accounting software, this can be handled in reports simply by sorting on vendor instead of category. Even the emphasis on category instead of vendor directs thought away from with whom the money is being spent and towards how the money is spent instead. Our mindsets are not towards localization.

Despite these challenges, these tools should be considered useful. Even a superficial examination of studies of the economic impacts of localization reveals disconnects with public statements about how much communities benefit from that localization. Uneducated estimates of how often a dollar circulates can be radically wrong, which does not help the localization effort. Combining social network analysis and Markov chains creates the ability to identify linkage and leakage within the local community and quantitatively determine if changes are in the best direction. This can be applied to the distribution of grants by community groups managing the natural resource, or to evaluate the costs of offering tax breaks to new industry.

As discussed earlier, inequitable distribution of benefits is a significant threat to sustainable community-based management of a natural resource. Applying mapping and the Gini coefficient to the distribution of access to the resource as well as to contracts for hired extraction might reveal a lack of equitable distribution within a community. This has political implications, and potentially threatens any local elite that may have gained control of the institution managing the resource and are benefiting from the arrangement.

Sustainable management of natural resources requires the management of people. We have inherent ideas about fairness, and when that fairness is missing everyone is worse off. As discussed, social ills such as teen pregnancy, alcoholism and mental illness all increase in less equal societies. It may seem antithetical to measure fairness, and this paper does not really attempt to do so. However, by measuring the circulation of a dollar in a community and measuring the distribution of benefits of extracting natural resources, this paper does attempt to create benchmarks by which communities can quantify their efforts and measure themselves.

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