Measuring Central Place Hierarchies in Multi-Regional Input-Output Systems

M. Henry Robison,
Senior Economist

Jonathan Crapuchettes,
Senior Economic I-O Programmer

Paper Presented at the International Input-Output Association Conference, Alexandria, Virginia, June, 2011

Economic Modeling Specialists, Inc.
1187 Alturas Dr.
Moscow, ID 83843 USA
www.economicmodeling.com

Introduction

While multi-regional input-output (MRIO) and central place theory (CPT) are both constructed on the basis of trade across distinct regions in space, there is little mixing of the two methodologies in the professional literature. Exceptions include Mulligan's (1979) formal expression of the central place-based city size model "… along lines consonant with input-output analysis." Later Robison and Miller 1991, and Robison, 1997 specifically construct MRIO models that convey central place architectures. And most recently, Sonis (2007) uses IO multiplier decomposition techniques to formally express the structure of idealized central place systems in terms of an otherwise standard MRIO framework.

The gulf separating CPT and MRIO may be ending. The rapid advance of computer technologies in the last several years means that fully-detailed MRIO models that were little more than theoretical ideals just a decade or two ago are now readily available and perhaps soon even commonplace.

In the first part of this paper we cast basic elements of CPT in MRIO terms and derive a simple expression for measuring the presence and extent of central place hierarchies. We turn next to a large-scale and just recently available MRIO data set covering all 3,000+ counties of the United States and empirically test our central place measure in case study fashion focused on three spatially diverse multi-area regions. We follow our empirical explorations with a discussion of the central place measure, and its use in defining functional economic areas.

Central Place Theory

Prior to Walter Christaller's 1933 publication of ***Central Places in Southern Germany*** (English translation, Christaller, 1966), geographers lacked any structured explanation as to the size and placement of settlements in space. Their observed arrangement was supposed to be shaped by the location of harbors, rivers, natural resources and such, but otherwise reflect no particular configuration, no particular pattern or architecture.

Christaller showed how settlements of varying sizes are arranged according to a specific overlapping hierarchy of market areas, a web of interlocking sub-areas commonly depicted in the formal literature by the multi-layered hexagonal net. Somewhat later, though independent of Christaller, August Losch (1954) applied a microeconomic analysis to arrive at essentially the same hierarchal structure though more thoroughly described.

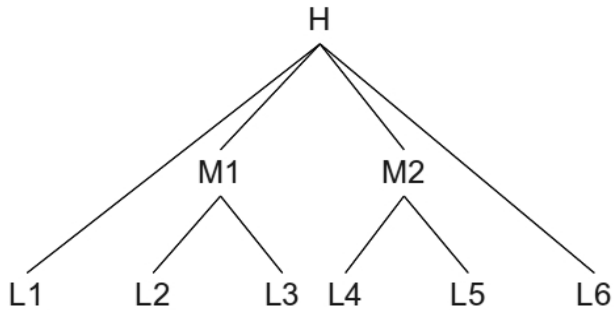
A sampling of work spawned by the central place theories of Christaller and Losch include Beckmann's city-size model and its many variants (see Beckmann, 1958 for the original, and Berry and Parr, 1988 for a summary of offsprings), work aimed at measuring the varying "centrality" of neighboring places in regional space (e.g., Davies, 1967), and empirical work aimed at measuring multipliers in central place hierarchies (e.g., Olfert and Stable, 1999 use a Keynesian multiplier framework while Robison et al., 1994 use MRIO multipliers). While very different one from another, these works all share a common a view of areal space exhibiting the familiar architecture of central place theory.

Christaller's Strict Trade Hierarchy

According to Christaller, settlements (places) of varying size are ordered and located according to the goods they provide to themselves and to other places. Lowest-order places supply themselves with a relative handful of goods, and obtain all others from higher-order places. Higher-order places supply themselves with lower-order goods, plus an additional layer of goods that define their specific hierarchical level. These additional goods are as well exported to a collection of surrounding lower-order places. Higher-order places are said to "dominate" the places that rely on them for higher-order goods. The highest-order place supplies itself with all lower-order goods, plus a unique layer of goods only available at the highest-order place. And the highest-order place dominates the entire system with regard to the highest-order goods. Two important features of Christaller's strict hierarchy: 1) places of the same order do not trade with each other and 2) goods flow down but never up the hierarchy (e.g., Seninger 1978).

The simple stick diagram in Figure 1 illustrates a 3-order strict Christaller system. Place H is the single highest-order place. Places M1 and M2 are 2^{nd}-order places, while places L1 through L6 are lowest-order (1^{st}-order) places. Lines connecting places indicate the higher- to lower-order flow of goods. Place H supplies the whole system (i.e., dominates the whole system) with its unique H-bundle of goods and supplies places L1 and L6 with the M-bundle (order-2 bundle) as well. Not shown for clarity but implicit are lines running directly from place H to places L2 through L5 indicating the flow of H-bundle goods. All places supply their own L-bundle (order-1) of goods.

Figure 1: Christaller Trade Hierarchy



The Figure 1 example of strict Christaller trade is easily portrayed in terms of an MRIO transactions matrix. The "regions" of this otherwise traditional matrix are Figure 2's several "places." The upper triangularity of the matrix assures the hierarchically downward-only flow of goods as required for a strict Christaller hierarchy. We use the term **C** to denote non-zero trade between two places. The main diagonal is shaded out: our analysis focuses on trade across regions and intra-regional trade plays no role.

Figure 2: MRIO Schematic, Inter-Area Transactions Matrix
Chrisaller Strictly Hierarchical Trade

	H	L1	L2	M1	L3	L4	M2	L5	L6
H		**C**	**C**	**C**	**C**	**C**	**C**	**C**	**C**
L1	-		-	-	-	-	-	-	-
L2	-	-		-	-	-	-	-	-
M1	-	-	-		**C**	**C**	-	-	-
L3	-	-	-	-		-	-	-	-
L4	-	-	-	-	-		-	-	-
M2	-	-	-	-	-	-		**C**	**C**
L5	-	-	-	-	-	-	-		-
L6	-	-	-	-	-	-	-	-	

Non-Christaller Trade

Christaller's rigidly structured picture of the regional landscape captures what is arguably the essential element of central place architecture, but it is clearly incomplete. To begin with, where do lowest-order places get the funds to purchase higher-order goods? Parr (1987) completes the picture by recognizing two types of goods, "central place" and "specialized." In general, central place goods are more or less ubiquitously demanded: groceries, consumer durables, movies, air travel, accounting, legal and business services, and so on. In contrast, "specialized goods" are items with production limited to specific locations: agricultural products, timber, input-oriented manufacturing, military installations, federal government offices, and so on. And there is commuting, a unique category of specialized good, in this case the good is actually a service, i.e., the services of labor.

A functioning regional economy will include trade in both types of goods. Besides trade in central place goods, as envisioned in Christaller's highly idealized model, lowest-order places derive income from the export of specialized goods to other places, often for further processing, or outside the larger region. Higher-order places derive their income from the supply of higher-order central place goods to lower-order places, as per Christaller, and from the export of specialized goods to other places and to outside the larger region. Figure 3 shows the multi-regional system as envisioned by Parr (1987), with **C** denoting central place goods and **n** denoting non-central place, specialized goods.

Figure 3: MRIO Schematic, Inter-Area Transactions Matrix
Parr "Specilaized" and "Central Place" Trade

	H	L1	L2	M1	L3	L4	M2	L5	L6
H		**C**	**C**	**C**	**C**	**C**	**C**	**C**	**C**
L1	n		n	n	n	n	n	n	n
L2	n	n		n	n	n	n	n	n
M1	n	n	n		**C**	**C**	n	n	n
L3	n	n	n	n		n	n	n	n
L4	n	n	n	n	n		n	n	n
M2	n	n	n	n	n	n		**C**	**C**
L5	n	n	n	n	n	n	n		n
L6	n	n	n	n	n	n	n	n	

Measuring Central Place Architectures

In this section we introduce a measure indicting the degree to which internal trade exhibits a central place architecture. The "central place measure" is built from terms drawn from MRIO accounts and reflects trade consistent with Christaller's strict central place hierarchy.

Defining Terms

From the accounts of an MRIO model, let **MT** equal the sum total of all interregional trade, i.e., the sum of all non-intraregional trade. Next, let $\mathbf{OT_c}$ be the sum of observed trade in what we term the "central place cells," i.e., cells that would indicate a strict Christaller trade hierarchy. In Figures 2 and 3, the central place cells are those containing **C**'s. Meanwhile let $\mathbf{OT_n}$ equal the sum of observed trade in remaining off-diagonal cells, i.e., trade in the non-central place cells. In Figure 3, these are the cells containing **n**'s. Note that in the special case of the matrix shown in Figure 2, i.e., a trade matrix that exhibits a strict Christaller hierarchy, $\mathbf{OT_n = 0}$. Note also that in the general case, $\mathbf{MT} = \mathbf{OT_c} + \mathbf{OT_n}$.

Next let us introduce the third idealized matrix shown in Figure 4. Here all cells contain the same value, **e**, which simply equals the average value of all off-diagonal cells. We might compute **e** as the sum of all off-diagonal trade divided by the number of off-diagonal cells. Observe that Figure 4 conveys no spatial pattern of trade, save perhaps that of the blank canvas. We will refer to this as the "maximum entropy matrix."

Figure 4: MRIO Schematic, Inter-Area Transactions Matrix
Maximum Entropy Assumption

	H	L1	L2	M1	L3	L4	M2	L5	L6
H		e	e	e	e	e	e	e	e
L1	e		e	e	e	e	e	e	e
L2	e	e		e	e	e	e	e	e
M1	e	e	e		e	e	e	e	e
L3	e	e	e	e		e	e	e	e
L4	e	e	e	e	e		e	e	e
M2	e	e	e	e	e	e		e	e
L5	e	e	e	e	e	e	e		e
L6	e	e	e	e	e	e	e	e	

Percent of Maximum Entropy

Let $\mathbf{ET_n}$ equal the sum of all terms **e** occupying non-central place cells. Equation (1) shows the observed trade in the non-central place cells as a portion of their maximum entropy value – the percent of non-central place trade.

(1) $\mathbf{\%N = OT_n/ET_n}$

Where trade is strictly hierarchical, as in Figure 2, the percent of non-central place trade equals zero.

The Central Place Measure

Finally, let us define the mathematical complement of equation (1):

(2) $\mathbf{\%C} = 1 - \mathbf{\%N}$

as the "percent central place measure," or more simply, the "central place measure." With application of a little algebra, the central place measure of equation (2) is alternatively expressed in the more instructive form:

(3) **%C** = (**OTc** – **ETc**)/(**MT** – **ETc**)

Equation (3) shows trade in central place cells in excess of their maximum entropy value, i.e., as a percent of their maximum potential excess over maximum entropy. In the case of trade that is strictly hierarchical (e.g., Figure 2), the percent of central place measure equals 100%.

Discussion

The central place measure is proposed as indicating the presence and degree of hierarchical order among the subregions of an MRIO system. How large must it be to be deemed "significant?" We leave that to outcome of empirical work. Observe, however, that a more or less large **%C** value is not an absolutely necessary condition for the presence of central place architecture.

The exceptions that deny **%C** standing as a necessary condition pertain to the potential for large amounts of so-called "specialized trade" (i.e., non-hierarchical trade) among subregions. As a simple example, imagine an elementary 2-order region with a single economically well developed center, i.e., a center exhibiting a wide range of resident-serving industries, dominating a surrounding peripheral region with few resident-serving industries. Suppose the peripheral region hosts a large contingent of primary industries, mining, timber, farming and such, and that these goods are shipped up the trade hierarchy for processing. Though a strong central place dominance exists between core and periphery, the up-hierarchy flow blunts a large value for **%C**.

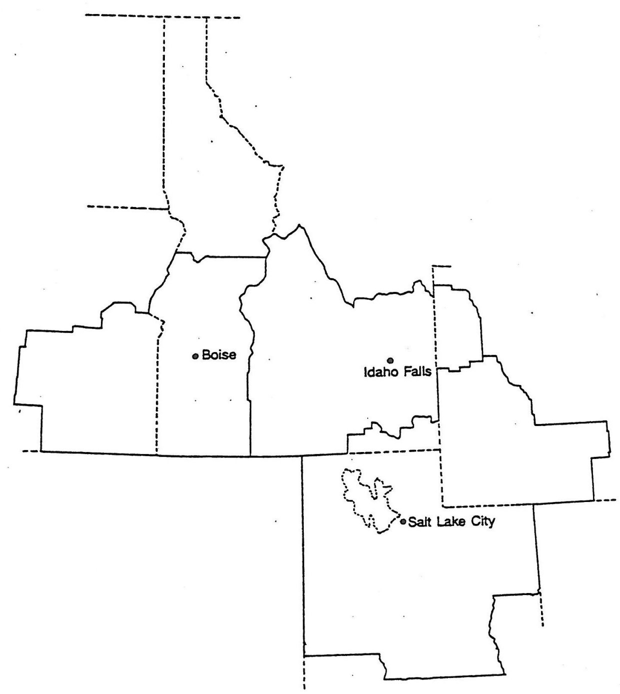
Case Study 1: The Salt Lake City-Centered Functional Economic Area

In this section we compare two empirical exercises in MRIO modeling. Two distinct years, built on different assumptions, but otherwise modeling the same MRIO system of core-periphery subregions. The first is drawn from Robison et al. (1994), refers to the economy in 1987, and assumes a Christaller strictly hierarchical structure. The second was produced with the just recently available EMSI Multi-Regional SAM Model (see: EMSI, 2011). It refers to the economy in 2010. Trade in the second model is unrestricted. Our analysis compares the two MRIO results and illustrates the central place measure.

Defining Subregions

Work by U.S. Department of Commerce, Bureau of Economic Analysis (BEA) to "map the principal trading areas of the U.S. economy" provides convenient and sensible building blocks for constructing central placed-based MRIO models. "BEA Economic Areas" are centered on dominant trading cores (a Christaller principle) and internally display relatively closed markets for labor and the business and consumer goods available there.

FIGURE 5
Economic and Political Boundaries of the Intermountain West



Robison et al. (1994) used BEA Economic Areas and defined sub-areas to examine spatial relationships in a northern Utah-southeastern Idaho economy centered on Salt Lake City, Utah. Figure 5 presents the BEA's mapping of the Intermountain West. Among other indications, the veracity of the BEA's trade regions is reflected in local-coverage television market areas as an indication of trade dominance. Southwestern Wyoming, for example, receives local-coverage Salt Lake City television, and Teton County, Wyoming receives local-coverage Idaho Falls television.

The BEA's mapping of U.S. trade areas is limited by its implicit two-order core-periphery structure. For example, while the reach of local-coverage Idaho Falls television corroborates the Idaho Falls trade area, local-coverage Salt Lake City television also is available throughout the Idaho Falls trade area. The larger area thereby exhibits a three-order trade hierarchy, with Salt Lake City at the top of the overall hierarchy, followed by Idaho Falls at the top of its own two-order trade hierarchy, followed by a collection of lowest-order peripheral subregions, either directly dominated by Salt Lake City or by both Salt Lake City and Idaho Falls.

FIGURE 6
Salt Lake City/Idaho Falls Trade Area

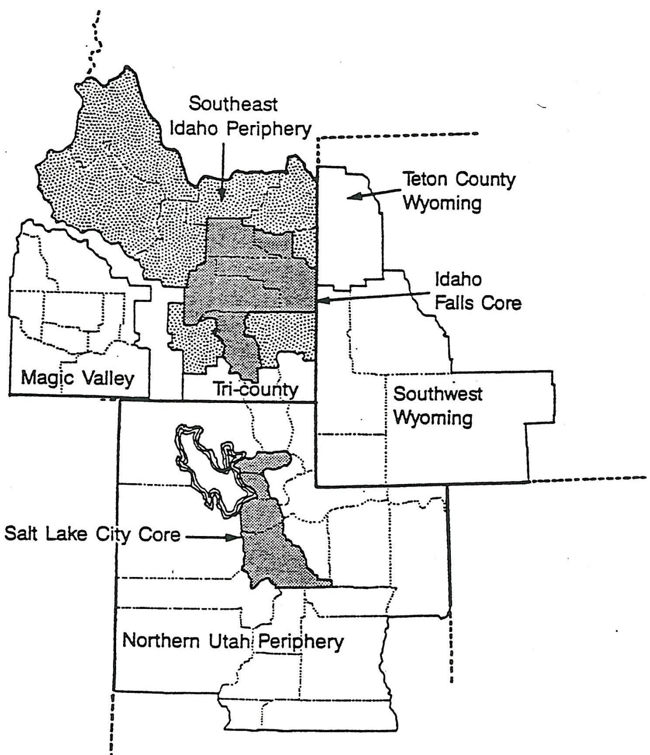


Figure 6 presents the Robison et al. (1994) subregional breakdown of the Intermountain West's three-order trade hierarchy. The "Salt Lake City core" reflects a more or less continuous urban-suburban complex, locally known as the "Wasatch Front" –Provo City, Salt Lake City, and Ogden City, Utah. The dark shaded area labeled "Idaho Falls core" reflects an urban-suburban complex that includes the cities of Pocatello, Blackfoot, Idaho Falls, Rigby, and Rexburg, Idaho.

Peripheral subregions are in part segmented according to political boundaries. Accordingly, the "Teton County, Wyoming Periphery" is separated from the "Southwest Idaho Periphery," while the "Tri-County (Idaho)" area is separated from what otherswise would be the Salt Lake City Periphery. "Magic Valley's" extraction from what would otherwise be part of an unbroken southeastern Idaho periphery reflects its relative size and independence.

Comparison of the Two Studies

Tables 1 and 2 are interregional transactions matrices drawn from the two MRIO models. The matrices are constructed from full interindustry/interregional tables by aggregating all industries into a single entry per region. The table below gives full regional titles for the shorthand notation shown in Tables 1 and 2.

Subregion	Notation
Salt Lake City Core (Utah Core)	UC
Northern Utah Periphery	UP
Southwest Wyoming Periphery	SW
TriCounty	TC
Southeast Idaho Periphery	IP
Teton County, Wyoming Periphery	TE
Magic Valley	MG
Idaho Falls Core (Idaho Core)	IC

The first thing to note is the obvious adoption of a Christaller strict hierarchy in the 1987 model (Table 1). As per that assumption, only the central place cells, i.e., shaded cells, contain non-zero elements in the off-diagonal. All other trade (in Parr's scheme, "specialized trade") is zero.

Table 2 presents trade as indicated in the EMSI MRIO SAM model. Notice the same pattern of assumed trade dominance, i.e., Salt Lake City and Idaho Falls, as indicated by shaded cells. However, off diagonal cells are now fully populated with what we will consider non-central place trade.

Table 3 conveys values collected from MRIO transactions Tables 1 and 2 as needed to compute our central place measure equation (3). The "Total OD (off-diagonal) Transactions" is simply equation (3)'s **MT**. "Maximum Entropy Transactions" for "Central Place Cells" refer to $\mathbf{ET_c}$, while for "Non-Central Place Cells" refer to $\mathbf{ET_n}$. "Observed Transactions" for "Central Place Cells" refer to $\mathbf{OT_c}$, while "Non-Central Place Cells" refer to $\mathbf{OT_n}$.

The "Central Place Measure" is computed from the other Table 3 components as per equation (3). Given the 1987 model's assumption of a strict Christaller trade hierarchy, the finding of a 100% central place measure is not interesting except as illustration. The finding from the 2010 model, with unrestricted trade, is of more interest. Does the computed value of 41% indicate a strong underlying presence of a central place architecture? We might suggest yes, but the conclusion is better made in comparison to other regions.

Table 1: Multiregional trade flows in the Salt Lake City-Centered FEA, as per the 1994 Robison et al. study (millions of 1987 dollars)

	UC	UP	TC	SW	IC	IP	TE	MG
UC	$23,052	$706	$30	$463	$68	$172	$30	$116
UP	$0	$5,052	$0	$0	$0	$0	$0	$0
TC	$0	$0	$175	$0	$0	$0	$0	$0
SW	$0	$0	$0	$2,674	$0	$0	$0	$0
IC	$0	$0	$0	$0	$3,041	$231	$34	$250
IP	$0	$0	$0	$0	$0	$1,423	$0	$0
TE	$0	$0	$0	$0	$0	$0	$379	$0
MG	$0	$0	$0	$0	$0	$0	$0	$2,825

Table 2: Multiregional trade flows in trade flows in the Salt Lake City-Centered FEA, as per the 2010 EMSI multi-regional I-O modeling system (millions of 2010 dollars)

	UC	UP	TC	SW	IC	IP	TE	MG
UC	$75,985	$5,168	$84	$156	$132	$68	$31	$107
UP	$4,710	$9,055	$22	$43	$25	$15	$6	$19
TC	$97	$52	$261	$1	$21	$12	$1	$1
SW	$53	$28	$1	$4,846	$14	$23	$91	$8
IC	$73	$37	$25	$24	$7,033	$782	$21	$37
IP	$37	$13	$4	$38	$246	$1,997	$28	$8
TE	$9	$7	$1	$276	$9	$37	$1,475	$1
MG	$58	$29	$2	$5	$29	$18	$2	$5,800

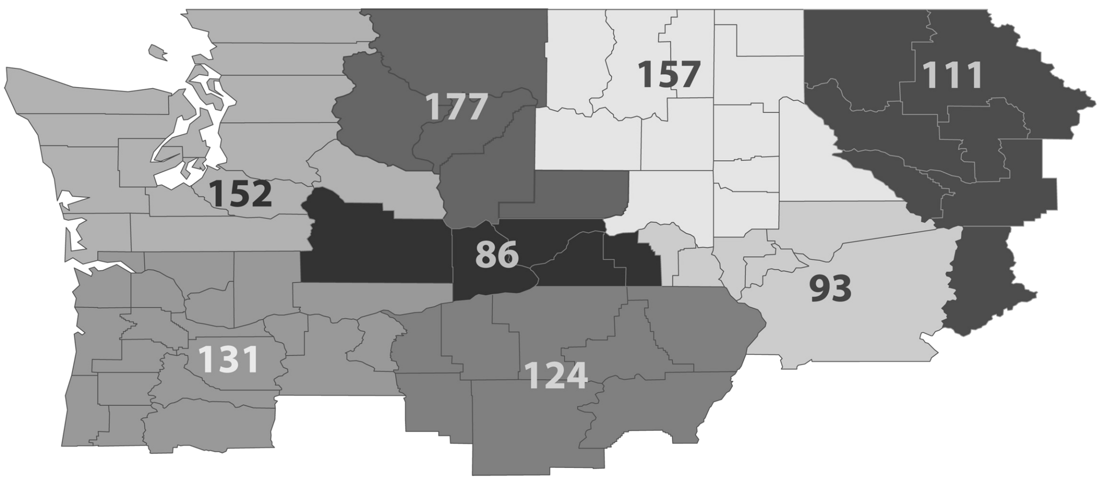
Table 3: Computing the Central Place Measure
Salt Lake City FEA, 1994 and 2011 MRIO models

	1994 Model 1987 dollars millions	2011 Model 2010 dollars millions
Total OD Transactions	$2,099	$12,842
Maximum Entropy Transactions		
Cental Place Cells	$375	$2,293
Non-Central Placer Cells	$1,724	$10,549
Observed Transactions		
Central Place Cells	$2,099	$6,586
Non-Central Placer Cells	$0	$6,257
Central Place Measure	100%	41%

Case Study 2: The Seattle-Centered Functional Economic Area

Population-wise, Seattle, Washington is roughly three-times as large as Salt Lake City, Utah (Seattle: 608, 000, Salt Lake City: 186,000) and it is reasonable to expect its market reach is larger as well. Based on the transportation network, local coverage television availability, and local knowledge, we propose boundaries for the Seattle Functional Economic Area as indicated in Figure 7.

Figure 7: Seattle Functional Economic Area



Map Key

86 Kennewick-Richland-Pasco, WA
93 Lewiston, ID-WA
111 Missoula, MT
124 Pendleton-Hermiston, OR
131 Portland-Vancouver-Beaverton, OR-WA
152 Seattle-Tacoma-Olympia, WA
157 Spokane, WA
177 Wenatchee, WA

Table 4: Multiregional trade flows in the Seattle-Centered FEA, as per the 2010 EMSI multi-regional I-O modeling system (millions of 2010 dollars)

	SEAC	SEAP	SPKC	SPKP	LEWC	LEWP	MSLC	MSLP	PTLC	PTLP	PNDC	PNDP	TRIC	TRIP	WENC	WENP
SEAC	$220,752	$13,172	$459	$257	$72	$42	$105	$200	$2,050	$376	$127	$78	$640	$98	$185	$268
SEAP	$10,792	$3,185	$8	$19	$5	$3	$2	$9	$112	$55	$7	$5	$44	$10	$7	$17
SPKC	$503	$90	$20,120	$2,490	$16	$7	$15	$32	$120	$28	$13	$10	$58	$16	$16	$41
SPKP	$209	$49	$1,809	$1,982	$6	$4	$4	$14	$46	$16	$4	$4	$24	$10	$5	$16
LEWC	$55	$16	$18	$12	$1,468	$157	$3	$4	$12	$5	$3	$3	$15	$8	$3	$7
LEWP	$22	$6	$2	$3	$161	$353	$1	$1	$6	$2	$0	$1	$3	$2	$0	$2
MSLC	$76	$20	$8	$9	$2	$2	$3,309	$1,136	$19	$6	$2	$2	$10	$3	$2	$6
MSLP	$142	$38	$11	$20	$3	$3	$877	$3,934	$34	$12	$3	$3	$16	$5	$3	$10
PTLC	$3,273	$776	$176	$111	$38	$19	$34	$74	$126,011	$2,688	$71	$46	$455	$72	$81	$128
PTLP	$286	$129	$22	$14	$5	$3	$2	$7	$3,542	$921	$6	$5	$40	$10	$10	$15
PNDC	$123	$23	$14	$8	$3	$1	$3	$4	$48	$12	$1,878	$299	$40	$13	$5	$12
PNDP	$47	$12	$3	$4	$3	$1	$1	$2	$17	$8	$419	$867	$7	$5	$1	$3
TRIC	$635	$167	$91	$56	$15	$8	$10	$22	$260	$77	$36	$18	$13,517	$652	$25	$58
TRIP	$83	$17	$13	$7	$3	$1	$2	$3	$36	$7	$12	$3	$1,065	$1,089	$3	$10
WENC	$172	$42	$42	$6	$1	$1	$1	$3	$36	$12	$2	$2	$10	$5	$2,481	$589
WENP	$220	$48	$20	$16	$4	$2	$2	$5	$40	$18	$11	$4	$48	$13	$452	$2,392

Subregion	Notation	Subregion	Notation
Seattle Core	SEAC	Portland Core	PTLC
Seattle Periphery	SEAP	Portland Periphery	PTLP
Spokane Core	SPKC	Pendleton Core	PNDC
Spokane Periphery	SPKP	Pendleton Periphery	PNDP
Lewiston Core	LEWC	Wenatchee Core	WENC
Lewiston Periphery	LEWP	Wenatchee Periphery	WENP
Missoula Core	MSLC	Tri-Cities Core	TRIC
Missoula Periphery	MSLP	Tri-Cities Periphery	TRIP

The subregions shown in Figure 7 are BEA Economic Areas. We in turn model these with core-periphery detail. The "core" of BEA Economic Areas are counties and county-combinations the BEA has identified as either "Metropolitan Areas (usually Standard Metropolitan Statistical Areas)," or what they term "Metropolitan Nodes." Table 4 presents the MRIO transactions matrix obtained from the EMSI MRIO model by aggregating all industry detail. Conceptually the table is the same as the MRIO transaction matrices shown for the Salt Lake City FEA, shown in Tables 1 and 2. Like the Salt Lake City matrices, patterns of central place trade dominance are shown in cells shaded gray.

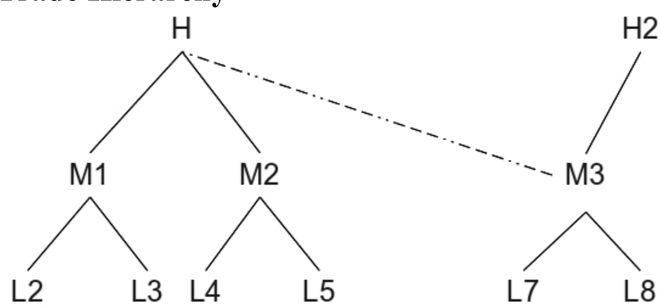
Reflecting our most basic central place view of this particular landscape, Seattle is assumed to trade dominate the entire region. Spokane, Washington is assumed to dominate its own immediate periphery, plus core-periphery regions for Lewiston, Idaho and Missoula, Montana. Similarly, Portland, Oregon is assumed to dominate its own immediate periphery, plus core-periphery regions for the "Tri-Cities" area of central-Washington (Richland, Pasco, Kennewick), and Pendleton, Oregon.

Adjusting for Area Boundary Effects

In formulating our central place measure (equation (3)) we have to this point ignored a potentially significant issue. The issue is familiar in regional science and pertains to outer boundaries, where one region ends and another begins. Unlike areas (say counties) near the trading center, where spatial dominance is fundamentally undisputed and complete, these outer areas will appear in the partial market shadow of two regions; part of the penumbra that inevitably separates economic regions in space.

The problem is conveyed visually via the simple additions shown in Figure 8 to the stick diagram of Figure 1. Here a second highest-order place, H2, dominates a new middle-order place, M3, which in turn dominates two additional lowest-order places, L7 and L8. There may or may not be actual dominance from our original highest-order center H, hence the dashed cord connecting H and M3. The important point is that if the boundaries of the H region are drawn to uncritically include M3, L7 and L8, then regardless of how weak the cord from H to M3, or how strong the cord from H2 to M3, the trade between M3 and its subcenters (L7 and L8) will be erroneously counted in equation (3) in support of a central place architecture centered on place H when in fact it more likely supports an architecture centered on place H2.

Figure 8: Border Issues in the Christaller Trade Hierarchy



What is needed is a way to subordinate the role of lower-order places. For example, in our three-order hierarchy, we need a way to discount the role of trade between places M and L according to the overarching trade between place H and places M. In the case illustrated in Figure 8, trade between M1, M2 and their level L subregions will be given weight that reflects the size of the H to M1 and H to M2 links. At the same time, the links between M3 and its L-level subregions will be given diminished or even no role, according to the small size, including zero, of the H to M3 link.

Our solution to the boundary effect problem then is to discount all but the direct highest-order trades, i.e., trades originating in place H, according to the lower-order place portion of overall H trades. An example will help illustrate the procedure. The top row of Table 4 (not counting the main diagonal) shows sales from the Seattle core to the various subregions of the MRIO system. Summing these cells, $13,172 million through

$268 million equals $14,363 million (not shown in the table). Of this total, sales to the Spokane core and periphery equal $717 million, or 4.8% of the $14,363 million total. In arriving at our value for observed central place trade, **OT_c,** we discount central place trade from the Spokane core (the sum of $2,490 million through $32 million) by counting only 4.8% in our estimate of **OT_c.** The remaining 95.2% of Spokane core to dominated subregion trade is considered part of non-central place trade, and included in **OT_n.** Other things equal, this maneuver will naturally lower our central place measure. In our estimates below we compute the central place measure with and without the adjustment so as to analyze its specific effect.

Measuring the Central Place Hierarchy

Table 5 presents results of our central place measures for various configurations of the Seattle dominated subregions of Figure 7. Columns indicate the configurations. We start in column 1 with the highest-order core subregion, the narrowly defined Seattle core-periphery region shown in Figure 7 as BEA Economic Area number 152. We refer to this subregion in isolation as "Seattle Small." Maintaining contiguity, we proceed to enlarge the geographic region, adding one core-periphery subregion at a time, until we obtain in column 8 results for the full multi-state Seattle Functional Economic Area depicted in Figure 7.

Table 5 rows show the various components needed to compute the central place measure. The first row shows the sum of off-diagonal cells, **MT**. The "Maximum Entropy Transactions" include **ET_c** for the central place cells, and **ET_n** for the non-central place cells. "Observed Transactions" include **OT_c** for the central place cells, and **OT_n** for the non-central place cells. Applying the discount procedure described in the previous section, components of **OT_c** reflecting patterns of lower-order place dominance are

Table 5: Computing the Central Place Measure, Seattle FEA and select Subregions

	Seattle Small	plus Wenatchee	plus Tri-Cities	plus Spokane	plus Lewiston	plus Missoula	plus Portland	Full Region
	(millions 2010 dollars)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Total OD Transactions	$23,964	$25,963	$29,546	$35,876	$36,561	$39,401	$54,796	$56,416
Maximum Entropy Transactions								
Cental Place Cells	$11,982	$8,654	$6,894	$6,407	$6,094	$5,970	$7,527	$7,052
Non-Central Placer Cells	$11,982	$17,309	$22,652	$29,470	$30,468	$33,431	$47,269	$49,364
Observed Transactions								
Central Place Cells	$13,172	$13,644	$14,415	$15,248	$15,363	$15,689	$18,525	$18,742
Non-Central Placer Cells	$10,792	$12,319	$15,132	$20,629	$21,198	$23,712	$36,271	$37,674
Central Place Measure								
Adjusted Measure	10%	29%	33%	30%	30%	29%	23%	24%
Full Measure	10%	32%	38%	42%	43%	44%	40%	40%

reduced according to their share of overall highest-order trade. Conversely, the value of non-central place trade, $\mathbf{OT_n}$, is increased.

Table 5's final section shows the central place measures. We report the "adjusted" measure first, reflecting the process of discounting described above. This is followed by the "full measure," reflecting our original procedure. Notice at the outset the 40% magnitude shown for the unadjusted full measure computed for the "Full Region." This compares closely to the 41% shown for the Salt Lake City Functional Economic Area as reported in Table 3.

Focusing now on column 1, the central place measures for the simple core-periphery "Seattle Small" region are reported at 10% each. With only one dominated subregion (the Seattle periphery), the discounting procedure has no play. As for the small value, 10%, this reflects the limited possibilities for exhibiting a central place architecture in the simple two-region MRIO. In column 2 we add the Wenatchee region. Note that discounting comes into play, 29% discounted versus 32% for the full measure. Wenatchee is a closely neighboring subregion of Seattle and thoroughly dominated by Seattle. Adding it seems to expand the central place content of the region.

Adding the “Tri-Cities” (Richland, Pasco, Kennewick) further expands the central place content, with a discounted central place measure of 33%. Proceeding east across Spokane, Lewiston and finally Missoula results in some diminishment of the discounted measure, down to 29%, but we would argue not enough to constitute a significant reduction.

Finally in column 7 the Portland, Oregon region is added along with its immediate periphery, and in column 8 we add the Portland-dominated subregion centered on Pendleton, Oregon. Here the decline in the adjusted central place measure is more pronounced, from the neighborhood of 30% without Portland/Pendleton, to 23% with Portland/Pendleton. The suggestion is that while areas to the east as far as Missoula are appropriately included in a Seattle-centered functional economic area, perhaps the boundaries to the south should stop short of the Portland and Pendleton areas. Perhaps a more appropriate course is to build up a Portland-centered region of its own, independent of Seattle.

Not shown in Table 5 are simulations adding still further regions to the east, southeast and south. As would be expected, beyond the subregions shown in the Table 5 adjusted central place measures fall off rapidly.

Case Study 3: The Idaho State Political Region Model

State and county boundaries in the United States are mainly artifacts of 19th century politics and typically bear little resemblance to contemporary economic boundaries (Fox and Kumar, 1965). Of the uses for central place-based MRIO, identifying economic regions is certainly an important one. Demonstrating the lack of correspondence between political and economic regions is a variant of region identification work.

Figure 9 shows the political and economic boundaries of Idaho. Solid lines show economic areas identified by the BEA, while dashed lines indicate state boundaries. To the north, Spokane, Washington dominates all of north Idaho, while to the southwest; Salt Lake City, Utah dominates all of southeastern Idaho. Idaho's largest city and state capitol, Boise, dominates southwestern Idaho and southwestern Oregon. The figure gives reason to a familiar saying: "Idaho has three capitols only one of which is located in Idaho.

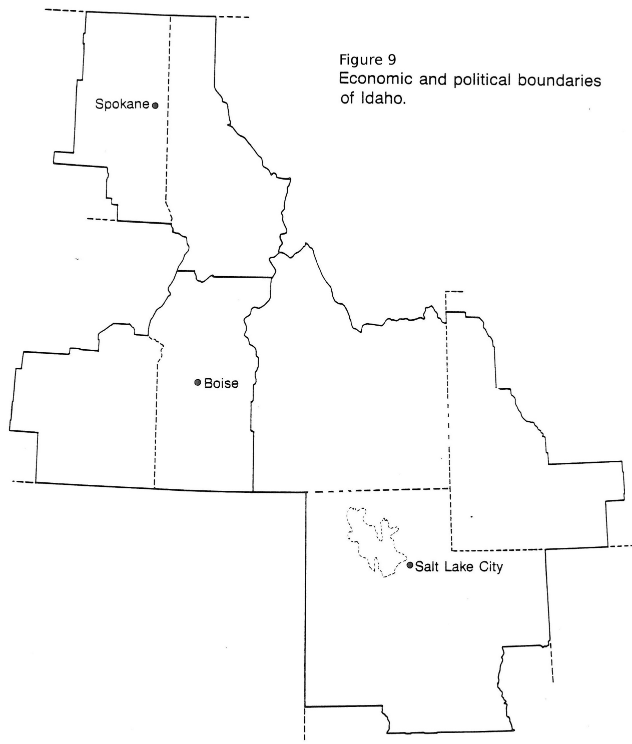


Figure 9
Economic and political boundaries of Idaho.

Table 6 presents an MRIO transactions matrix for Idaho. The spatial structure includes four subregions, one for north Idaho, one for southwestern Idaho, one for southeastern Idaho, and one for the Magic Valley. Each subregion is in turn broken into a dual region core-periphery structure.

Table 6: Multiregional trade flows among Suregions of Idaho (millions of 2010 dollars)

	SWC	SWP	EIC	EIP	NIC	NIP	MVC	MVP
SWC	$20,712.30	$1,333.06	$6.71	$31.48	$7.04	$20.65	$8.96	$24.02
SWP	$1,011.53	$478.43	$0.54	$5.65	$0.73	$5.28	$0.47	$5.74
EIC	$4.00	$2.86	$2,419.18	$1,302.64	$0.96	$2.64	$1.41	$4.53
EIP	$31.90	$22.78	$890.65	$4,560.66	$3.52	$10.98	$6.33	$25.47
NIC	$4.79	$3.40	$0.49	$3.24	$1,891.83	$368.85	$0.54	$1.96
NIP	$13.63	$9.74	$2.20	$9.81	$312.53	$2,442.33	$2.34	$6.38
MVC	$5.35	$4.80	$1.69	$8.85	$0.72	$2.24	$1,916.05	$725.64
MVP	$13.54	$14.49	$2.13	$17.91	$1.97	$5.31	$636.07	$3,099.01

Subregion	Notation
Southwestern Idaho Core (Boise)	SWC
Southwestern Idaho Periphery	SWP
Eastern Idaho Core	EIC
Eastern Idaho Periphery	EIP
North Idaho Core	NIC
North Idaho Periphery	NIP
Magic Valley Core	MVC
Magic Valley Periphery	MVP

Boise is the state's largest city and state capitol, and so might be presumed to dominate the entire state. Boise's assumed dominance is reflected in Table 6's top row gray shaded cells. Beyond this, the only other pattern of central place dominance occurs within core-periphery subregions. This is reflected in shaded gray cells for each of the several periphery subareas.

Table 7 shows the calculation of the central place measure for Idaho. First note that at 45% the full unadjusted measure is quite high. Our discounting procedure dramatically reduces this to just 18%. It is instructive to consider what discounting does in the case of the Idaho MRIO.

Table 7: Computing the Central Place Measure
Idaho State MRIO, 2010

	millions 2010 dollars
Total OD Transactions	$6,953
Maximum Entropy Transactions	
Cental Place Cells	$1,242
Non-Central Placer Cells	$5,712
Observed Transactions	
Central Place Cells	$2,281
Non-Central Placer Cells	$4,673
Central Place Measure	
Adjusted	18%
Full Measure	45%

Core over periphery dominance is significant in each of the several subregions. In the southeastern Idaho case, core (EIC) sales to periphery (EIP) amounts to $1.3 billion. In the unadjusted full central place measure, this trade is counted as part of a Boise-centered Idaho state central place architecture. In fact, southeastern Idaho is economically oriented to Salt Lake City and not Boise. Discounting serves to correct for these errors.

So we take the 18% discounted measure as evidence that the state boundaries of Idaho make a poor economic area. For the important work of policy formation, the analyst is well to bear this in mind. A single non-spatial model constructed for Idaho will likely overstate multiplier effects in northern and southeastern Idaho, where multiplier affects leak to either Washington or Utah, and understate impacts in southwestern Idaho. A more sensible approach would model each of the several regions separately, or better still, employ a full MRIO framework that incorporates the spatial pattern of multiplier effects.

Conclusions

This paper has focused on the internal structure of regions with the particular aim of identifying functional economic areas. CPT provides us a theoretical ideal and we use terms from otherwise traditional MRIO models to measure the correspondence of actual regions against the ideal. We offer a simple term, "the central place measure," as an indicator of the presence of central place architecture.

We illustrate our theoretical work through three case studies. The first focuses on a combined Utah-Idaho region centered on Salt Lake City. Here we compare results from an earlier study that assumed strictly hierarchical trade with the results drawn from more recent modeling utilizing a full MRIO data set. Our measure provides evidence of central place structures in the Salt Lake City-centered economy.

Our second case study focused on a multi-state region centered on Seattle, Washington. After modifying our measure to better account for boundary issues, we examine alternative regional configurations in a test of our initial regional view. We find that the optimal region is likely smaller than the one that might be supposed by the unaided application of theory and local knowledge.

Finally, we apply our analysis to the case of a region that lacks functional economic characteristics. Idaho's political boundaries are widely recognized as lacking regional economic logic, i.e., Idaho makes a poor functional economic area. As expected, we apply our central place measure to Idaho and get the poorest result yet for the central place measure. We conclude by cautioning against the use in policy analysis of a single region IO model for Idaho. Here smaller area or a full MRIO framework should be employed.

Given the limited extent of the paper and its three case studies, we must view the work as preliminary. Additional case studies should be added, and additional theoretical work should be considered on the effects of aggregation, both regional and industry. An important promise of the MRIO-CPT integrating effort is to make the many insights of CPT available for applied studies, and to provide an objective means for identifying economic regions.

Bibliography

Beckmann, M.J., 1958. "City Hierarchies and the Distribution of City Size," ***Economic Development and Cultural Change***, 6, 243-248.

Berry, B.J.L., J.B. Parr, B.J. Epstein, A. Ghosh, and R.H.T. Smith, 1988. ***Market Centers and Retail Location, Theory and Applications***, (Englewood Cliffs, Prentice Hall).

Christaller, W., 1966. ***Central Places in Southern Germany*** (C.W. Baskins, trans.). Englewood Cliffs, N.J., Prentice Hall.

Davies, W.K.D., 1967. "Centrality and the Central Place Hierarchy." ***Urban Studies***, 4, 61-79.

Fox, K.A. and K. Kumar. 1965. "The Functional Economic Area: Delineation and Implications for Economic Analysis and Policy," ***Papers of Regional Science Association***, 15, 57-85.

Losch, A., 1954. ***The Economics of Location*** (W.H. Woglom and W.F. Stolper, trans.). New Haven: Yale University Press.

Olfert, M.R. and J.C. Stabler. 1999. "Multiplier in a Central Place Hierarchy," ***Growth and Change***, 30, 288-302.

Mulligan, G.F., 1979. "Additional Properties of a Hierarchical City-Size Model," ***Journal of Regional Science***, 19(1), 57-66.

Parr, J.B., 1987. "Interaction in an Urban System: Aspects of Trade and Commuting," ***Economic Geography***, 63(3), 223-240.

Robison, M.H. 1997. "Community Input-Output Models for Rural Area Analysis: with an Example from Central Idaho," ***Annals of Regional Science***, 31(3), 325-351.

Robison, M.H., J.R. Hamilton, K.P. Connaughton, N. Meyer and R. Coupal. 1994. "Spatial Diffusion of Economic Impacts and Development Benefits in Hierarchically Structured Trade Regions: An Empirical Application of Central Place-Based Input-Output Analysis," ***Review of Regional Studies***, 23(3), 307-326.

Robison, M.H. and J.R. Miller. 1991. "Central Place Theory and Community Input-Output Analysis," ***Papers in Regional Science***, 70(4), 399-417.

Seninger, S.F., 1978. "Expenditure Diffusion in Central Place Hierarchies: Regional Policy and Planning Aspects," ***Journal of Regional Science***, 18, 243-261.

Sonis, M., 2007. "Central Place Theory after Christaller and Losch: Some further Exploration," in ***Space-Structure-Economy: A Tribute to August Losch***. Nomos: Munich