Updating and Estimating a Social Accounting Matrix Using Cross Entropy Methods

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Abstract

The problem in estimating a social accounting matrix (SAM) for a recent year is to find an efficient and cost-effective way to incorporate and reconcile information from a variety of sources, including data from prior years. Based on information theory, the paper presents a flexible "cross entropy" (CE) approach to estimating a consistent SAM starting from inconsistent data estimated with error, a common experience in many countries. The method represents an efficient information processing rule—using only and all information available. It allows incorporating errors in variables, inequality constraints, and prior knowledge about any part of the SAM. An example is presented applying the CE approach to data from Mozambique, using a Monte Carlo approach to compare the CE approach to the standard RAS method and to evaluate the gains in precision from utilizing additional information.

KEYWORDS: Entropy, cross entropy, social accounting matrices, SAM, input- output, RAS, Monte Carlo simulations

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1. Introduction

There is a continuing need to use recent and consistent multisectoral economic data to support policy analysis and the development of economywide models. A Social Accounting Matrix (SAM) provides the underlying data framework for this type of model and analysis. A SAM includes both input-output and national income and product accounts in a consistent framework. Estimating a SAM for a recent year is a difficult and challenging problem. Input-output data are usually prepared only every five years or so, while national income and product data are produced annually, but with a lag. To produce a more disaggregated SAM for detailed policy analysis, these data are often supplemented by other information from a variety of sources; *e.g.*, censuses of manufacturing, labor surveys, agricultural data, government accounts, international trade accounts, and household surveys. The problem in estimating a disaggregated SAM for a recent year is to find an efficient (and cost-effective) way to incorporate and reconcile information from a variety of sources, including data from prior years.

A standard approach is to start with a consistent SAM for a particular prior period and "update" it for a later period, given new information on row and column totals, but no information on the flows within the SAM. The traditional RAS approach, discussed below, addresses this case. However, in practice, one often starts from an inconsistent SAM, with incomplete knowledge about both row and column sums and flows within the SAM. Inconsistencies can arise from measurement errors, incompatible data sources, or lack of data. What is needed is an approach to estimating a consistent set of accounts that not only uses the existing information efficiently, but also is flexible enough to incorporate information about various parts of the SAM.

In this paper, we propose a flexible "cross entropy" (CE) approach to estimating a consistent SAM starting from inconsistent data estimated with error. The method is very flexible, incorporating errors in variables, inequality constraints, and prior knowledge about any part of the SAM (not just row and column sums). The next section presents the structure of a SAM and a mathematical description of the estimation problem. The following section describes the RAS

procedure, followed by a discussion of the cross entropy approach. Next we present an application to Mozambique demonstrating gains from using increasing amounts of information.[2]

2. Structure of a Social Accounting Matrix (SAM)

A SAM is a square matrix whose corresponding columns and rows present the expenditure and receipt accounts of economic actors. Each cell represents a payment from a column account to a row account. Define **T** as the matrix of SAM transactions, where $t_{i,j}$ is a payment from column account j to row account i. Following the conventions of double-entry bookkeeping, total receipts (income) and expenditure of each actor must balance. That is, for a SAM, every row sum must equal the corresponding column sum:

$$y_i = \sum_j t_{i,j} = \sum_j t_{j,i} \tag{1}$$

Where y_i is total receipts and expenditures of account i.

A SAM coefficient matrix, **A**, is constructed from **T** by dividing the cells in each column of **T** by the column sums:

$$a_{i,j} = \frac{t_{i,j}}{y_j} \tag{2}$$

By definition, all the column sums of **A** must equal one, so the matrix is singular. Since column sums must equal row sums, it also follows that (in matrix notation):

$$\mathbf{y} = \mathbf{A}\mathbf{y} \tag{3}$$

A typical national SAM includes accounts for production (activities), commodities, factors of production, and various actors ("institutions"), which receive income and demand goods. The structure of a simple SAM is given in Table 1. Activities pay for intermediate inputs, factors of production, and indirect taxes, and receive payments for sales of their output. The commodity account buys goods from activities (producers) and the rest of the world (imports),

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[2] An appendix with the computer code in the GAMS language used in the procedure is available upon request. The method has been used to estimate SAM's for a number of African countries (Botswana, Malawi, Mozambique, Tanzania, Zambia, and Zimbabwe) and a few other countries (e.g., Brazil, Mexico, North Korea, and the United States). The Mozambique application is described below.

and pays tariffs on imported goods, while it sells commodities to activities (intermediate inputs) and final demanders (households, government, investment, and the rest of the world). In this SAM, gross domestic product (GDP) at factor cost equals payments by activities to factors of production, or value added. GDP at market prices equals GDP at factor cost plus indirect taxes and tariffs, which also equals total final demand (consumption, investment, and government) plus exports minus imports.

<< Table 1 >>

The matrix of column coefficients, **A**, from such a SAM provides raw material for much economic analysis and modeling. For example, the intermediate-input coefficients (computed from the "use" matrix) are Leontief input-output coefficients. The coefficients for primary factors are "value added" coefficients and give the distribution of factor income. Column coefficients for the commodity accounts represent domestic and import shares, while those for the various final demanders provide expenditure shares. There is a long tradition of work which starts from the assumption that these various coefficients are fixed, and then develops various linear multiplier models. The data also provide the starting point for estimating parameters of nonlinear, neoclassical production functions, factor-demand functions, and household expenditure functions.

In principle, it is possible to have negative transactions, and hence coefficients, in a SAM. Such negative entries, however, can cause problems in some of the estimation techniques described below and also may cause problems of interpretation in the coefficients. A simple approach to dealing with this issue is to treat a negative expenditure as a positive receipt or a negative receipt as a positive expenditure. That is, if $t_{i,j}$ is negative, we simply set the entry to zero and add the value to $t_{j,i}$. This "flipping" procedure will change row and column sums, but they will still be equal.

3. The RAS Approach to SAM Updating

The classic problem in SAM estimation is the problem of "updating" an input-output matrix when we have new information on the row and column sums, but do not have new

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information on the input-output flows. The generalization to a full SAM, rather than just the input-output table, is the following problem. Find a new SAM coefficient matrix, $\mathbf{A}^*$, that is in some sense "close" to an existing coefficient matrix, $\overline{\mathbf{A}}$, but yields a SAM transactions matrix, $\mathbf{T}^*$, with the new row and column sums. That is:

$$t_{i,j}^* = a_{i,j}^* y_j^* \tag{4}$$

$$\sum_j t_{i,j}^* = \sum_j t_{j,i}^* = y_i^* \tag{5}$$

Where $\mathbf{y}^*$ are known new row and column sums.

A classic approach to solving this problem is to generate a new matrix $\mathbf{A}^*$ from the old matrix $\overline{\mathbf{A}}$ by means of "biproportional" row and column operations:

$$a_{i,j}^* = r_i \, \overline{a}_{i,j} \, s_j \tag{6}$$

or, in matrix terms:

$$\mathbf{A}^* = \hat{\mathbf{R}} \overline{\mathbf{A}} \hat{\mathbf{S}} \tag{7}$$

where the hat indicates a diagonal matrix of elements r_i and s_j. Bacharach (1970) shows that this "RAS" method works in that a unique set of positive multipliers (normalized) exists that satisfies the biproportionality condition and that the elements of $\hat{\mathbf{R}}$ and $\hat{\mathbf{S}}$ can be found by a simple iterative procedure.[3]

4. A Cross Entropy Approach to SAM estimation

The estimation problem is that, for an n-by-n SAM, we seek to identify n^2 unknown non-negative parameters (the cells of $\mathbf{T}$ or $\mathbf{A}$), but have only 2n–1 independent row and column adding-up restrictions. The RAS procedure imposes the biproportionality condition, so the

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[3]For the method to work, the matrix must be "connected," which is a generalization of the notion of "indecomposable" (Bacharach, 1970, p. 47). For example, this method fails when a column or row of zeros exists because it cannot be proportionately adjusted to sum to a non-zero number. Note also that the matrix need not be square. The method can be applied to any matrix with known row and column sums: for example, an input-output matrix that includes final demand columns (and is hence rectangular). In this case, the column coefficients for the final demand accounts represent expenditure shares and the new data are final demand aggregates.

problem reduces to finding $2n-1$ r_i and s_j coefficients (one being set by normalization), yielding a unique solution. The general problem is that of estimating a set of parameters with little information. If all we know are row and column sums, there is not enough information to identify the coefficients, let alone provide degrees of freedom for estimation. Updating, in this framework, becomes a special case of the more general estimation problem for which the information provided is the balanced SAM to be updated and new row and column totals.

In a recent book, Golan, Judge, and Miller (1996) suggest a variety of estimation techniques using "maximum entropy econometrics" to handle such "ill-conditioned" estimation problems. Golan, Judge, and Robinson (1994) apply this approach to estimating a new input-output table given knowledge about row and column sums of the transactions matrix—the classic RAS problem discussed above. We extend this methodology to situations where there are different kinds of prior information than knowledge of row and column sums.

4.1. Deterministic Approach: Information Theory

The estimation philosophy adopted in this paper is to use *all*, and *only*, the information available for the estimation problem at hand. The first step we take in this section is to define what is meant by "information". We then describe the kinds of information that can be incorporated and how to do it. This section focuses on information concerning non-stochastic variables while the next section will introduce the use of information on stochastic variables.

The starting point for the cross entropy approach is information theory as developed by Shannon (1948). Theil (1967) brought this approach to economics. Consider a set of n events E_1, E_2, …, E_n with probabilities $q_1, q_2,…, q_n$ (prior probabilities). A message comes in which implies that the odds have changed, transforming the prior probabilities into prior probabilities $p_1, p_2,…, p_n$. Suppose for a moment that the message confines itself to one event E_i. Following Shannon, the "information" received with the message is equal to -ln p_i. However, each E_i has its own prior probability q_i, and the "additional" information from p_i is given by:

$$-\ln \frac{p_i}{q_i} = -\left[\ln p_i - \ln q_i \right] \qquad (8)$$

Taking the expectation of the separate information values, we find that the *expected information* value of a message (or of data in a more general context) is

$$-I(p:q) = -\sum_{i=1}^{n} p_i \ln \frac{p_i}{q_i} \tag{9}$$

where *I(p:q)* is the Kullback-Leibler (1951) measure of the "cross entropy" (CE) distance between two probability distributions.[4] Kapur and Kenavasan (1992, Chapter 4) describe various axiomatic approaches that uniquely define the entropy measure as an appropriate measure of information and that justify the use of the CE measure for inference. For estimation, the approach is to find a set of *p's* that minimize the cross entropy between the probabilities and the prior *q's*, and that are consistent with the information in the data.[5]

Golan, Judge, and Robinson (1994) use a cross entropy formulation to estimate the coefficients in an input-output table. They set up the problem as finding a new set of *A* coefficients which minimizes the entropy distance between the prior $\overline{A}$ and the new estimated coefficient matrix.[6]

$$\min\left[\sum_i \sum_j a_{i,j} \ln \frac{a_{i,j}}{\overline{a}_{i,j}}\right] \tag{10}$$

Subject to:

$$\sum_j a_{i,j} y_j^* = y_i^* \tag{11}$$

$$\sum_j a_{j,i} = 1 \text{ and } 0 \le a_{j,i} \le 1 \tag{12}$$

The solution is obtained by setting up the Lagrangian for the above problem and solving it.[7] The outcome combines the information from the data and the prior:

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[4]Note that the cross-entropy "distance" is not a norm. It is neither symmetric nor satisfies the triangle inequality.

[5]If the prior distribution is uniform, representing total ignorance, the method is equivalent to the "Maximum Entropy" estimation criterion (see Kapur and Kesavan, 1992; pp. 151-161).

[6]The intuition underlying this minimization problem is that it aims to minimize the expected information value of additional data given what we know (sample and prior).

[7]The problem has to be solved numerically because no closed form solution exists.

$$a_{i,j} = \frac{\overline{a}_{i,j}\exp\left(\mathbf{1}_i y_j^*\right)}{\sum\limits_{i,j}\overline{a}_{i,j}\exp\left(\mathbf{1}_i y_j^*\right)} \tag{13}$$

where $\mathbf{1}_i$ are the Lagrange multipliers associated with the information on row and column sums, and the denominator is a normalization factor.

The expression is analogous to Bayes' Theorem, whereby the posterior distribution $(a_{i,j})$ is equal to the product of the prior distribution $(\overline{a}_{i,j})$ and the likelihood function (probability of drawing the data given parameters we are estimating), dividing by a normalization factor to convert relative probabilities into absolute ones. The analogy to Bayesian estimation is that the approach can be seen as an efficient Information Processing Rule (IPR) whereby we use additional information to revise an initial set of estimates (Zellner, 1988, 1990). In this approach an "efficient" estimator satisfies what Zellner (1988) describes as the "Information Conservation Principle": the estimation procedure should neither ignore any of the input information nor inject any false information. It can also be shown that the CE estimators are consistent and, given assumptions about the form of the underlying distribution, have maximum likelihood properties (Golan, Judge, and Miller, 1996).

4.2. Types of Information

Information for SAM estimation comes in many forms:

1. Priors. A SAM from an earlier year provides information about the new coefficients. The approach is to estimate a new set of coefficients "close" to the prior, using new information to "update" the prior.
2. Moment constraints. The most common kind of information to have is data on some or all of the row and column sums of the new SAM. Treating the column coefficients as analogous to probabilities, assuming known column sums in equation (11) is equivalent to knowing averages of the column sums, weighting by the coefficients—or first moments of the distributions. While the RAS procedure is based on knowing all row and column sums, it is only one of several possible sources of information in CE estimation.

3. Economic aggregates. In addition to row and column sums, one often has additional knowledge about the new SAM. For example, aggregate national accounts data may be available for various macro aggregates such as value added, consumption, investment, government, exports, and imports. There also may be information about some of the SAM accounts such as government receipts and expenditures. This information can be summarized as additional linear adding-up constraints on various elements of the SAM. Define an n-by-n aggregator matrix, **G**, which has ones for cells in the aggregate and zeros otherwise. Assume that there are k such aggregation constraints, which are given by:

$$\sum_i \sum_j g_{i,j}^{(k)} t_{i,j} = \boldsymbol{g}^{(k)} \tag{14}$$

where $\boldsymbol{g}$ is the value of the aggregate. These conditions are simply added to the constraint set in the cross entropy formulation. The conditions are linear in the coefficients and can be seen as additional moment constraints. Assuming known column sums is a special case of this general formulation.

4. Inequality constraints. While one may not have exact knowledge about values for various aggregates, including row and column sums, it may be possible to put bounds on some of these aggregates. Such bounds are easily incorporated by specifying inequality constraints in equations (11) and (14).

5. Zeros. Typically, a number of cells in a SAM are blank, indicating no flow. In the RAS method, the row and column operations guarantee that the updated SAM will contain zeros wherever the original SAM had zeros, and nonzero elements otherwise. Such constraints are also easily incorporated in the CE approach by constraining SAM entries to be zero in the estimation problem. However, it is also straightforward in the CE approach to allow zero elements in the prior to become nonzero in the estimated SAM, and vice versa. By convention, in information theory, a zero probability yields zero information: $x \log x = 0$ by assumption. In practice, in equation (10), we replace $a_{i,j}$ and $\bar{a}_{i,j}$ by $(a_{i,j} + \boldsymbol{d})$ and $(\bar{a}_{i,j} + \boldsymbol{d})$, where ä is a small positive number. Then the estimated values of the $a_{i,j}$ coefficients can be zero. Similarly, we can leave cell entries unconstrained, even though the prior values are zero, allowing the possibility of a

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nonzero entry appearing (say, drawing on information about possible technological changes in which the input-output coefficient matrix becomes more dense).

4.3. Stochastic Approach: Measurement Error

Most applications of economic models to real world issues must deal with the problem of extracting results from data or economic relationships with noise. In this section we generalize our approach to cases where: (i) row and column sums are not fixed parameters but involve errors in measurement; and (ii) the initial estimate, $\bar{\mathbf{A}}$, is not based on a balanced SAM. Consider the standard regression model:

$$\mathbf{y} = \mathbf{x}\,\hat{\mathbf{a}} + \mathbf{e} \tag{15}$$

where $\hat{\mathbf{a}}$ is the coefficient vector to be estimated, $\mathbf{y}$ represents the vector of dependent variables, $\mathbf{x}$ the independent variables, and e is the error term. Consider the standard assumptions made in regression analysis from the perspective of information theory.

- There is plenty of data providing adequate degrees of freedom for estimation.
- The error e is usually assumed to be normally distributed with zero mean and constant variance. This represents a lot of information on the error structure. The only parameter that needs to be estimated is the error variance. Given these assumptions, we need only use information in the form of certain moments of the data, which summarize all the information required to carry out efficient estimation: $\hat{\mathbf{a}} = \left(\mathbf{x}'\mathbf{x}\right)^{-1}\mathbf{x}'\mathbf{y}$
- On the other hand, no prior information is assumed about the parameters. The null hypothesis is $\hat{\mathbf{a}} = 0$, and we assume that no other information is available about $\hat{\mathbf{a}}$.
- The independent variables are non-stochastic, meaning that it is in principle possible to repeat the sample with the same independent variables.

These assumptions are extremely constraining when estimating a SAM because little is known about the error structure and data are scarce. SAM estimation is not a statistical model where the issue is specifying a random error generating process, but a problem of estimation in

the presence of measurement error.[8] Finally, data such as parameter values for previous years, which are often available when estimating a SAM, provide information about the current SAM, but this information cannot be put to productive use in the standard regression model. Compared to the standard model, we have little data and know little about the errors, but we have a lot of information in a variety of forms about the coefficients to be estimated.

There have been a number of efforts to apply statistical methods to SAM estimation. See, for example Barker *et al.* (1984), van der Ploeg (1982), and Toh (1998).The approach is to specify some kind of quadratic loss function and assume information about the statistical properties of the error distributions. Harrigan and Buchanan (1984) argue persuasively for the advantages of a constrained maximization estimation approach in terms of flexibility, but are aware of the statistical problems. Harrigan and McNicoll (1986) state (p. 1065) that "even where inequality restrictions give way to equalities, the assumptions required to sustain statistical interpretation are extremely demanding." Byron (1978) and Schneider and Zenios (1990) also argue in favor of a constrained maximization approach, and are also skeptical of imposing strong statistical assumptions.

Harrigan (1990) compares the use of a quadratic positive definite (QPD) objective function with the Kullback-Leibler cross-entropy (CE) measure. He concludes that both "possess the desirable property that they give posterior estimates which better reflect the unknown, true values than do the associated prior estimates." He then goes on to argue that one cannot prove the superiority of either the QPD or CE approaches in terms of the relative closeness of their posterior estimates to the true values, using either measure of closeness.[9] From the perspective of information theory, however, one can show that using any objective function other than the CE measure implicitly injects additional unwarranted information into the estimation procedure (Golan, Judge, and Miller, 1996). If the additional information is "correct," then the resulting

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[8]The problem is analogous to the distinction between errors in equations and errors in variables in standard regression analysis. See, for example, Judge *et al.* (1985). Golan and Vogel (1997) describe an errors in equations approach to the SAM estimation problem.

[9]One should note, however, that the distinction between the QPD and CE approaches is not necessarily great. Golan, Judge, and Miller (1996, pp 30-31) show that one can approximate the CE minimand using a weighted squared error measure.

estimators might be closer to the true values, but there is no prior reason to make such an assumption—the CE estimation principle is to use *all* but *only* the information available.

We extend the cross entropy criterion to include an "errors in variables" formulation where the independent variables are assumed to be measured with noise, as opposed to the "errors in equations" specification, where the process is assumed to include random noise. Rewrite the SAM equation and the row/column sum consistency constraints as:

$$\mathbf{y} = \mathbf{A}\left[\overline{\mathbf{x}} + \mathbf{e}\right] = \mathbf{A}\overline{\mathbf{x}} + \mathbf{A}\mathbf{e} \tag{16}$$

$$\mathbf{y} = \overline{\mathbf{x}} + \mathbf{e} \tag{17}$$

where $\mathbf{y}$ is the vector of row sums and $\overline{\mathbf{x}}$, measured with error $\mathbf{e}$, is the known vector of column sums, which represents our prior on the column and row sums. In our case, we assume that the initial column sums in the data are the best prior estimate. One could use alternative estimates (*e.g.* initial row sums). Equation 17 reflects the requirement that column and row sums must be equal. Following Golan, Judge, and Miller (1996, chapter 6), we write the errors as a weighted average of known constants as follows:

$$e_i = \sum_w w_{i,w} \overline{v}_{i,w} \tag{18}$$

subject to the weights being between zero and one, and summing to one:

$$\sum_w w_{i,w} = 1 \text{ and } 0 \leq w_{i,w} \leq 1 \tag{19}$$

In the estimation, the weights are treated as probabilities to be estimated. The constants, $\overline{\mathbf{v}}$, define the "support set" for the errors (using a bar to indicate that they are not variables) and, along with a specified prior for the weights, define a prior for the error distribution. The support set is usually chosen to yield a prior symmetric distribution with moments depending on the number of elements in the set $\mathbf{W}$. In general, one can add more v's and W's to incorporate more potential information about the error distribution (*e.g.*, more moments, including variance, skewness, and kurtosis). In our case, we specified a support set with three elements and a uniform prior for the weights. The support set is specified so that $\overline{v}_2 = 0$ and $\overline{v}_1 = -\overline{v}_3$, implying a prior on the error distribution with mean zero and variance $\mathbf{s}^2 = \sum_w w_w \overline{v}_w^2$. One can specify a separate prior for every error, if desired, but the main point is that it is only a prior, not a maintained hypothesis about the error distribution.

Given knowledge about the error bounds, equations (17), (18) and (19) are added to the constraint set and equation (16) replaces the SAM equation (equation 3). The problem is messier in that the SAM equation is now nonlinear, involving the product of **A** and **e**. The minimization problem is to find a set of A's and W's that minimize cross entropy including a term in the errors:

$$I\left(\mathbf{A}, \mathbf{W} : \overline{\mathbf{A}}\right) = \left[\sum_i \sum_j a_{i,j} \ln a_{i,j} - \sum_i \sum_j a_{i,j} \ln \overline{a}_{i,j}\right]$$
$$+ \left[\sum_i \sum_w w_{i,w} \ln w_{i,w} - \sum_i \sum_w w_{i,w} \ln \frac{1}{n}\right] \tag{20}$$

subject to the constraint equations that column and row sums be equal, and that the W's and A's fall between zero and one (where n is the number of elements in the error support set W, implying a uniform prior), and any other known aggregation inequalities or equalities.

Equation (20) is minimized with respect to the A's (SAM coefficients) and W's (weights on the error term), where the W's are treated like the A's. In the estimation procedure, the terms involving the A's and W's are assigned equal weights, reflecting an equal preference for "precision" (closeness to the prior A's) in the estimates of the parameters, and "prediction" (the W's or the "goodness of fit" of the equation on row and column sums). Golan, Judge, and Miller (1996) report Monte Carlo experiments where they explore the implications of changing these weights and conclude that equal weighting of precision and prediction is reasonable.

Another source of measurement error may arise if the initial SAM, $\overline{\mathbf{A}}$, is not itself a balanced SAM. That is, its corresponding rows and columns may not be equal. This situation does not change the cross entropy estimation procedure, but implies that it is not possible to achieve a cross entropy measure of zero because the prior is not feasible. The idea is to find a new feasible SAM that is "entropy-close" to the infeasible prior.

Finally, Golan, Judge, and Robinson (1994) discuss a specification where each element in the SAM is assumed to be measured with error. In this case, each element has a separate error component with a "weak" prior on its distribution in the sense of specifying only a support set. The result is that the procedure involves a large number of additional weights to be estimated, but generates measures of the precision of the estimates cell by cell. The approach is closely analogous to the approach suggested by Byron (1978) in which he assumes that one starts with detailed knowledge of the cell-by-cell error distributions, including means and variances. In the

CE approach, however, only very weak assumptions need be made about these error distributions.[10]

5. Updating a SAM: RAS and Cross-Entropy

To illustrate the use of the proposed cross entropy estimator and to compare its properties to that of the RAS method, we apply both methods to update a 1994 macro SAM for Mozambique (Table 2).[11] Monte Carlo simulations are carried out by starting from the balanced SAM and then randomly imposing new row and column totals. The SAM is then updated to be consistent with the new totals using both the RAS and the cross-entropy methods. Since we change only row and column totals, we have no idea what the "true" updated SAM should be and can therefore only compare the results of the two methods in terms of how different they are. We compare outcomes using two standard distance measures, the root mean squared deviation (RMSD) of either (1) the new SAM values or (2) its column coefficients, both relative to those of the original SAM.

As noted in the literature, the RAS and the cross-entropy methods are equivalent if the CE method uses as an objective a single cross-entropy measure (cell coefficients measured relative to the sum of all flows in the SAM) instead of using the sum of column cross-entropies (normalized relative to column totals).[12] Intuitively, the RAS method tries to maintain the value structure (flow-dependent) while the CE method seeks to maintain the coefficient structure (column-coefficient-dependent).[13] Assuming the same information (knowledge of row/column sums), we would expect the RAS results to be closer to the original SAM values than the CE

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[10]In applying the CE method to SAM coefficients, one must take care when interpreting the resulting statistics because the parameters being estimated are not probabilities, although the column coefficients satisfy the same axioms. While such a procedure is common in the entropy estimation literature, the cell-by-cell approach taken in Golan, Judge, and Robinson (1994) does not rely on any assumptions about the nature of the coefficients. They found the estimated coefficients from the two approaches to be extremely close, and argued that the cell-by-cell approach was useful in yielding information about the reliability of each cell estimate.

[11]Arndt, et al. (1997) describe the Mozambique SAM in detail.

[12]See, for example, Bacharach (1970), Schneider and Zenios (1990), and McDougal (1999).

[13]McDougal (1999) shows that the RAS method is also equivalent to maximizing a weighted sum of the column-coefficient cross-entropies, where the weights are the row (or column) sum values. The RAS method can be seen as treating column and row coefficients symmetrically, and is a special case of the CE method.

method relative to the SAM flows. Similarly, the CE results should be closer to the original coefficient matrix.

If we are seeking to use the updated SAM to estimate column coefficients, which is commonly the case when the SAM is used to do multiplier analysis or provide various share coefficients for a CGE model, then it is desirable to express the information contained in the original SAM in terms of column coefficients, which *a priori* favors the CE approach. That is, the new estimates will be closer to the prior for the CE method, given the same additional information (in the form of new column/row sums). On the other hand, if primary interest is in the nominal flows, or if row coefficients are as important as column coefficients, then the RAS approach appears more desirable *a priori*. As noted above, the RAS method is a special case of the CE method, using a particular cross-entropy minimand and assuming only knowledge of row and column sums. So it is feasible to use the CE approach as a generalization of the RAS method when different types of information are available. An important question is whether the two approaches differ significantly in practice. If not, then it may not matter much which is used in most cases.

The procedure adopted for the Monte Carlo simulations is as follows: three row totals were randomly perturbed relative to the balanced Macro SAM, and the perturbed values were imposed as the new row and column totals in the updating process. The perturbed values were generated by sampling from a set of normal distributions with increasing standard deviations: the values starting from 1% and increasing up to 10% in 1% increments every 100 samples, making for a total of one thousand runs. Figure 1a is a scatter plot of the root mean square deviation (RMSD) of the SAM flows after updating relative to the initial flows. On the Y-axis is the RMSD obtained using the entropy method, while on the X-axis is the RMSD according to the RAS. The solid line at 45 degrees represents situations where the two methods give the same answer. The dotted line is a linear regression fitting the sample.

Figure 1a indicates that the RAS and CE methods perform similarly in flow terms. The points are grouped around the 45-degre line, with no strong differences in the degree to which the flow estimates deviate from the prior under the two approaches. The regression line is slightly above the 45-degree line, indicating that, as expected, the RAS method yields results closer to the prior flows, but the differences are not great.

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<<Figure 1>>

The results are very different when the two methods are compared in terms of deviation of the column coefficients after updating relative to the initial coefficients. Figure 1b unequivocally shows that, in terms of column coefficients, updating by the cross entropy method yields estimates much closer to the prior coefficients than updating with the RAS method. The dotted regression line indicates that the coefficient RMSD is about 25% lower using the cross entropy method than with the RAS.[14]

The conclusion to be drawn from the comparison of the RAS and the cross entropy method is that if the analyst is concerned column coefficients, then the cross entropy method appears superior to the RAS method. If, on the other hand, the focus is on the flows in the SAM, then the two methods are very close, with the RAS method performing slightly better.

6. From Updating to Estimating Using the Cross-Entropy Approach

In the previous section the comparison between cross entropy and RAS methods was made in the context of the standard updating problem found in the input-output literature. We now shift the focus to an application that illustrates a more general formulation of the updating problem: estimating a SAM given various data sources of varying quality. This is a process that is often done manually by applied researchers. We show, however, that the CE approach efficiently uses all the available information for SAM estimation. In fact, many of the manual operations (or data "adjustments") can be incorporated into the CE approach. Most importantly, the estimation problem is set in the context of information theory and the procedure generates measures of the "importance" of different data used in the estimation process.

The performance of the cross entropy method in this estimation process was tested, once again, by running Monte Carlo simulations. For one thousand simulations, at each run eight cells of the originally balanced SAM were chosen at random and perturbed. Each time, the unbalanced SAM obtained through this procedure was balanced using the cross entropy method. This procedure was performed assuming varying types of information were available: (i) in the first

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[14]It is interesting to observe that the pattern in the scatter plot of Figure 1b appears to be distributed along two different lines. This dual behavior is probably associated with different moment constraints becoming binding in the entropy method.

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set of simulations no information was assumed other than correspondong row and column sums must match, (ii) in the second set, select macroeconomic aggregates were assumed to be known, (iii) finally, in addition to some macroeconomic aggregates, row and column totals were assumed to be known, but with measurement error.

In these simulations, the CE estimates can be compared with the correct SAM, which provided the starting point for every perturbed simulation. As before, we use two root mean square distance measures, one for nominal flows and one for column coefficients. In this case, they measure the "error" from the correct value rather than the deviation of two measures, so we term them RMSE measures.

To underscore the flexibility of the cross entropy method and the estimation characteristics of this procedure compared to the RAS method, which requires information on row and column sums, the first attempt at balancing the SAM proceeds by assuming no information beyond the data in the unbalanced SAM. The results were therefore estimated under the assumption of no information except that corresponding row and column sums must be equal. In cross entropy method, only equations (11) and (12) are imposed as constraints (or equivalently, equations 1-8 in Appendix A with all error terms set to zero). This might be the situation an analyst faces when constructing a SAM after all data have been inserted. Due to the different data sources adopted, the SAM contains all available data but such data are inconsistent leading to imbalances in the SAM accounts. In such a situation, there is no balanced SAM available from a prior year, and hence no updating procedure can be used. What is needed is an estimation procedure. The estimation problem, however, is that data are sparse. There are certainly not enough degrees of freedom for standard statistical approaches such as least squares methods. There is, at best, one observation per parameter to be estimated (in our case, the SAM flows). The estimation problem is always "ill posed" in classical statistical terms. Economic knowledge is imposed through constraints such as, at a minimum, that corresponding row and column sums be equal.

Figure 2a presents the 95% confidence interval of the root mean square error (RMSE) of the flows relative to the correct (unperturbed) SAM in the no-extra-information case. Figure 2b presents the RMSE for the column coefficients. In both cases, on the x-axis are the standard deviations used in the sampling distribution of the perturbations imposed on the original SAM. One notices immediately that, as the standard deviation of the perturbation increases, so do the

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mean RMSE and the variance of such error. Notably, the relationships appears to be approximately linear with the standard deviation of the perturbation both when flow and coefficient error are considered.

<<Figure 2>>

The second set (Allfix) adds additional information assumed known from other sources. The additional information includes moment constraints on some row and column sums, inequality constraints, and knowledge of various economic aggregates like total consumption, exports, imports, and GDP at market prices (results in Fig. 3a and 4a). The third set of simulations (Allfix plus error) extends the second estimation method to include the "errors in variables" formulation, adding information on additional row and column sums assumed to be measured with error. For the error term (e_i), we specify an error support set with three elements centered on zero, allowing a two-parameter symmetric distribution with unknown mean and variance (results in fig. 3b and 4b). What is immediately apparent from these results is that, by incorporating different types of information (new constraints, and therefore greater degrees of freedom), the estimates obtained improve considerably judging from the RMSE. When looking at flows, if information is added, the RMSE decreases noticeably. For the Allfix scenario there is an approximately 30% decrease in the flow RMSE. When the column totals are introduced with error, in combination with Allfix, the results are even more dramatic, leading to an 80% reduction in the flow RMSE.

<<Figure 3>>
<<Figure 4>>

Similar results are observed on the coefficient side, and these are also easier to interpret since all coefficients are by definition in the [0,1] range. Figure 4 presents the RMSE of the column coefficients when information is added to the basic estimation procedure. The improvement is less dramatic than for the flows, especially when fixing flow values such as total consumption, exports, imports, and GDP at market prices. Figure 4a shows nearly no change in the deviation of the coefficients. This occurs because by fixing a flow, and leaving the column

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total associated with that flow free to vary, the coefficients tend to remain unchanged (since they appear in the objective function) and the total is adjusted (since it does not appear in the objective) so as to accommodate the new constraint on the fixed flow. However, one can see that if the column totals are assumed known with error (with the weights on the error term appearing in the objective), then the RMSE on the coefficients is reduced by as much as 50% in our example (see Figure 4b). This result highlights the importance of knowing the row or column totals, and in an environment where these totals are not known with certainty, the cross entropy specification with error can be extremely useful from an operational standpoint.

The cross-entropy measures reflect how much the information we have introduced has shifted our solution estimates away from the inconsistent prior, while also accounting for the imprecision of the moments assumed to be measured with error. Intuition suggests that if the information constraints are binding, the distance from the prior will increase; if none are binding, then the cross entropy (CE) distance will be zero. That is, there exists a $\mathbf{y}$, such that $\overline{\mathbf{A}}\mathbf{y} = \mathbf{y}$. In our Core case without any constraints on the y other than that column and row sums must be equal, a solution can be found without changing the column coefficients, as indicated by a CE measure of zero.[15] We observe that, as more information is imposed, the CE measure increases as expected (Figure 5a and 5b).

<<Figure 5>>

7. Conclusion

The cross entropy (CE) approach provides a flexible and powerful method for estimating a social accounting matrix (SAM) when dealing with scattered and inconsistent data. The method represents a considerable extension and generalization of the standard RAS method, which assumes that one starts from a consistent prior SAM and has knowledge only about new row and column totals. The CE framework allows a wide range of prior information to be used efficiently in estimation. Drawing on information theory, the cross-entropy approach is "efficient" in that it uses all available information, but only that information—no assumed information is injected

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[15] The CE measure associated with the error term is zero for the Core and AllFix cases because the error term is set to zero and the column totals are free to vary, so no binding constraint is imposed.

into the estimation procedure.The prior information can be in a variety of forms, including linear and nonlinear inequalities, errors in equations, and measurement error (using an error-in-variables formulation). One also need not start from a balanced or consistent SAM. The results from a variety of Monte Carlo experiments demonstrate the power of the CE approach and provide measures of the gains from incorporating a wide range of information from a variety of sources to improve our estimation of the SAM parameters.

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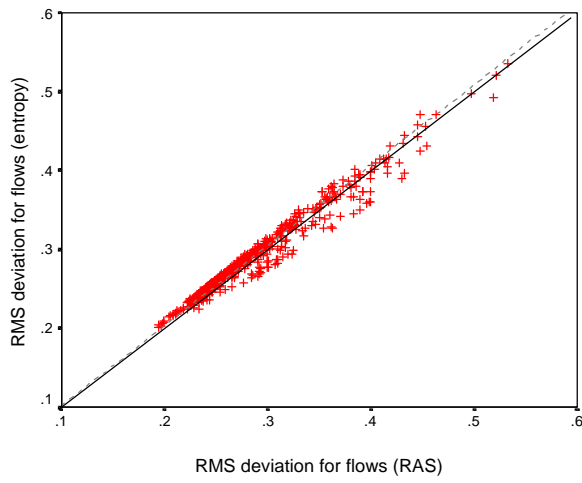
Table 1. A National SAM

Receipts	Expenditure				
	Activity	Commodity	Factors	Institutions	World
Activity		Domestic sales			
Commodity	Intermediate inputs			Final demand	Exports
Factors	Value added (wages/rentals)				
Institutions	Indirect taxes	Tariffs	Factor income		Capital inflow
World		Imports			
Totals	Total costs	Total absorption	Total factor income	Gross domestic income	Foreign exchange inflow

# Table 2. 1994 SAM for Mozambique (millions of 1994 Meticais)

Receipts	Expenditure (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	Totals
(1) Agr. activity			25.14				30.50						55.64
(2) Non-agr. activity			12.46	206.28			2.14						220.88
(3) Agr. Commodity	1.58	13.42					20.12		0.00		0.09	8.58	43.79
(4) Non-agr. Commodity	7.24	98.86					86.72	16.77	0.00	33.94	33.03	24.13	300.69
(5) Factors	47.01	108.74											155.75
(6) Enterprises					62.86								62.86
(7) Households					91.63	58.96		1.33				3.46	155.38
(8) Rec. govt.*			0.94	9.88	1.26	2.41	2.49						22.53
(9) Indirect tax	-0.19	-0.14	0.24	5.64									5.55
(10) Govt. investment												22.94	22.94
(11) Private investment						1.49	13.41	4.43		-11.00		24.79	33.12
(12) Rest of the world			5.01	78.89									83.90
Totals	55.64	220.88	43.79	300.69	155.75	62.86	155.38	22.53	5.55	22.94	33.12	83.90	1163.02

Source Arndt, C. et al., 1997
* Recurrent government expenditures

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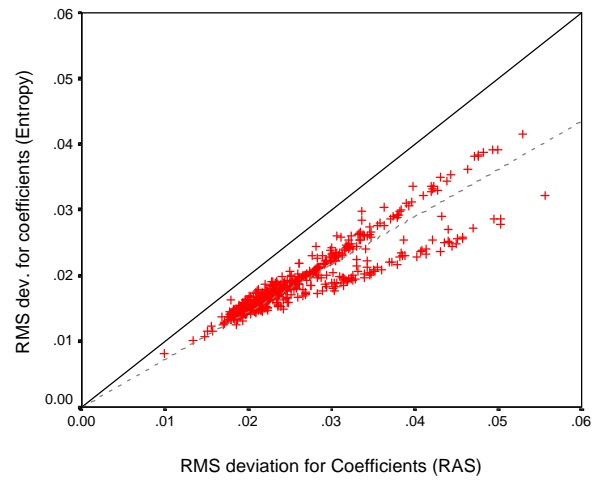
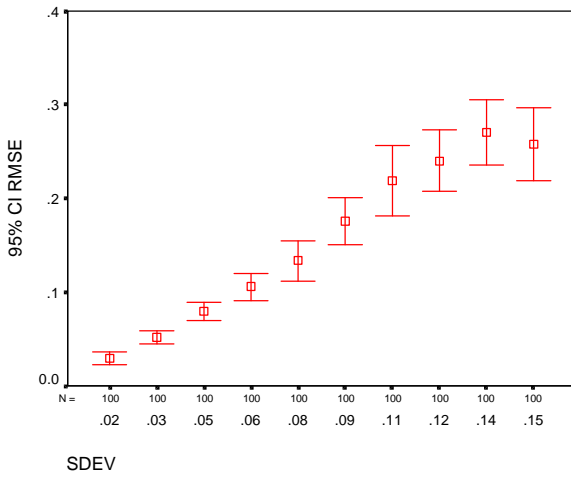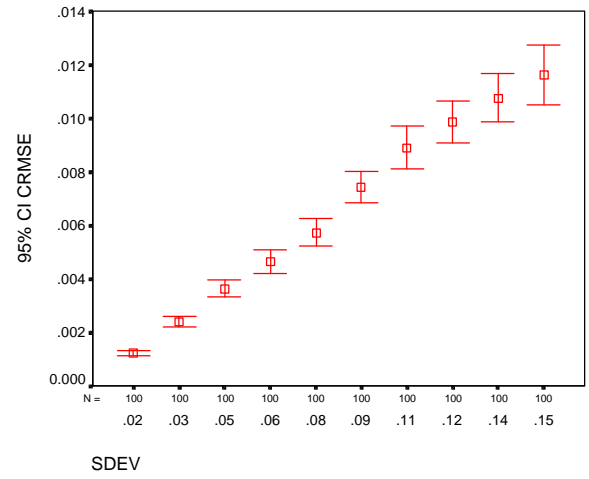**Figure 1. Comparison of the root mean square deviation relative to the initial SAM (for flows and coefficients).**
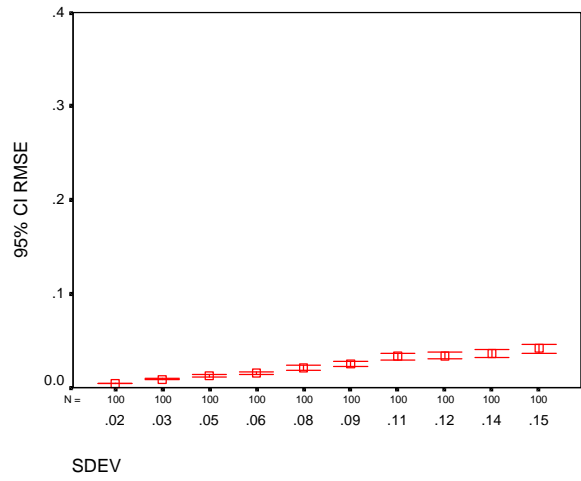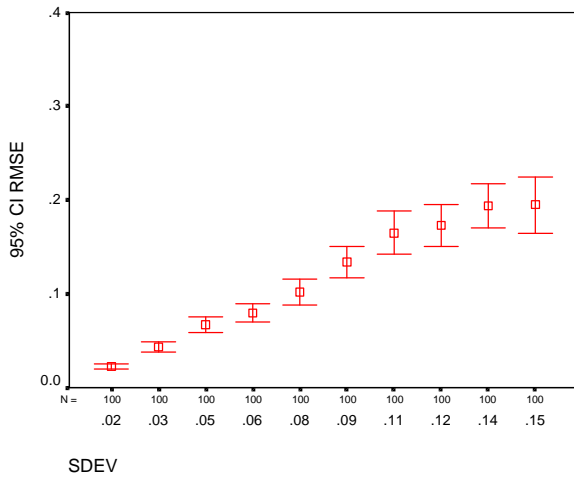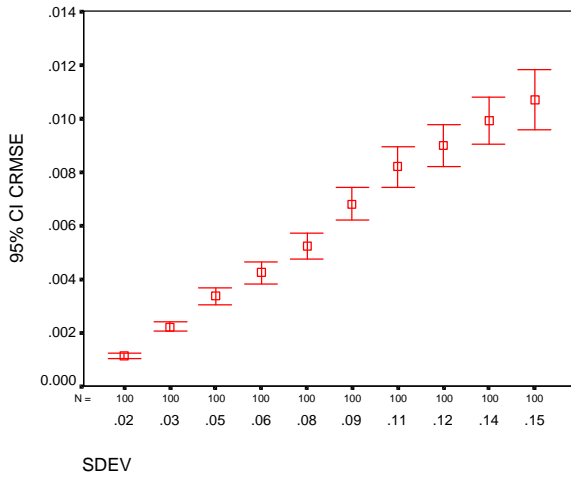
flows

(b) coefficients

Figure 2. Basic Estimation: 95% confidence interval for root mean square error after balancing with entropy method (relative to unperturbed SAM).
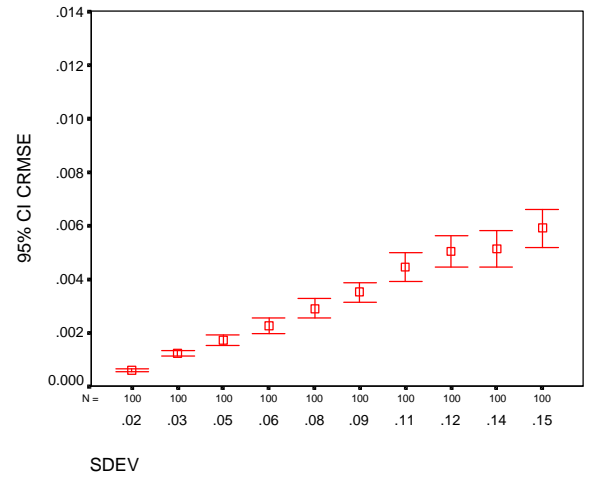
(a) allfix   **(b) allfix + totals with error**

Figure 3. Adding information: 95% confidence interval for root mean square error of <u>flows</u> after balancing with entropy method (relative to unperturbed SAM) .
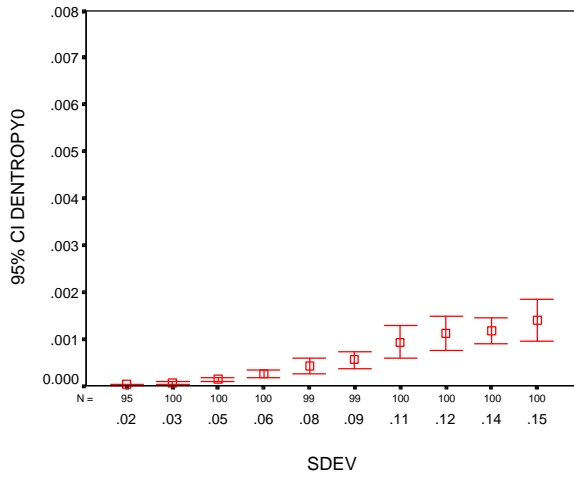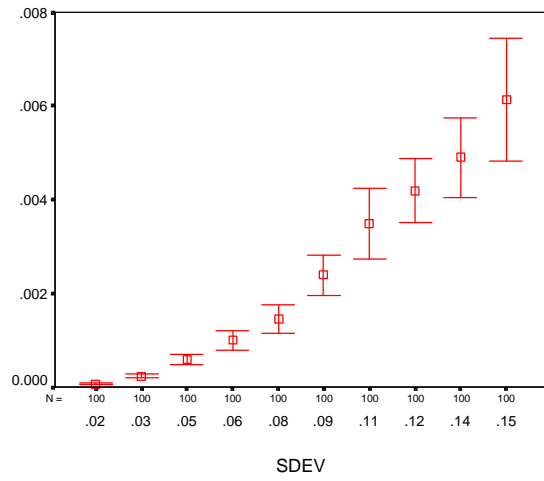
(a) allfix

(b) allfix + totals with error

Figure 4. Adding information: 95% confidence interval for root mean square error of <u>coefficients</u> after balancing with entropy method (relative to unperturbed SAM)

(a) allfix

(b) allfix + coltot + err

Figure 5. Adding information: Cross-Entropy comparison

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