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The Transaction Value Approach
A Systematic Method of Defining Economywide Models Based on Social Accounting Matrices

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THE TRANSACTION VALUE APPROACH: A SYSTEMATIC METHOD OF DEFINING ECONOMYWIDE MODELS BASED ON SOCIAL ACCOUNTING MATRICES

A. Drud, W. Grais, and G. Pyatt

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Abstract: The Social Accounting Matrix (SAM), a convenient way of giving a comprehensive and consistent picture of an economy, is used as the data base for many models. The paper describes the Transaction Value (TV) Approach, a systematic way of defining, estimating, and solving economywide multisectoral equilibrium models based on a SAM. SAM-based models define for each period a SAM with the same accounting structure as the base SAM. The behavioral equations of a SAM-based model are derived from independent descriptions of the economic agents, and the model is tied together by the accounting identities of the SAM. The TV approach has four advantages: the models are guaranteed to be consistent, it is easy to experiment with alternative formulations, most parameters can be estimated from the base SAM, and the underlying solution algorithm is guaranteed to converge under very general assumptions.

Key words: Social Accounting Matrices, Multisectoral Equilibrium Models, Developing Economies, Modeling Methodology, Consistency.

INTRODUCTION

This paper describes the Transaction Value (TV) approach, a method for defining, estimating, and solving a class of economywide general equilibrium models. It also describes SAMLIB, a corresponding software package. Developed at the World Bank, the TV-approach and SAMLIB have so far been used with more than ten models of various developing economies.

Since many general purpose econometric modeling systems are commercially available (Drud, 1983), we feel it is appropriate to explain why we have worked on yet another system. Previous systems have all been designed for use with econometric models of developed economies. Most of these systems assume, implicitly or explicitly, that the models describe economic processes. The mathematical requirement is that the model is normalized or in fixed-point format.

The time series for developing countries seldom are long enough to allow the sophisticated estimation of lag structures and dynamic behaviour needed in economic-process models. This is especially true for multisector models that are important in modeling economic development. The missing data must therefore be replaced by more theoretical content. A class of development planning models (Dervis, de Melo, and Robinson, 1982) has replaced the short-run dynamic process description by assumptions of medium term (within period) equilibrium in most markets. That reduces the dynamics of the models to the linkages between periods through a small number of such variables as debt, capital stock, and labor force composition.

Equilibrium models are mathematically formulated as a set of relations that equate demand and supply in different markets; they are not normalized. The prices that adjust to clear each market will in many models not appear directly in the market-clearing equation but only indirectly in expressions for supply and demand of intermediates. Equilibrium models can, like all nonsingular models, be normalized. But there is no natural normalization, and a method that always finds a convergent normalization is not yet known.

Because the modeling environment in developing countries differs much from standard macroeconomic modeling environments, it puts different demands on...
methods and software. Our objective has been to develop a method and a software system that can:

- help in formulating and representing equilibrium models,
- test the models for consistency,
- estimate parameters,
- solve the models reliably, and
- make it easy to change assumptions.

The paper is organized as follows. We first discuss our data base — the Social Accounting Matrix (SAM) — and continue with an example of a model based on a SAM. We then define the TV approach and describe our assumptions and the procedures for estimating parameters and solving the model. The overall method is summarized in the conclusion.

THE SOCIAL ACCOUNTING MATRIX
AS A DATA BASE

The first step in building an empirical model is to establish a consistent data base. Since our equilibrium models describe the whole circular flow in the economy, the most natural single-period description seems to be the SAM, which is a matrix representing the circular flow (Pyatt, Roe, and co-workers, 1977). The matrix of rows and columns is square with one row and one column, called accounts, for each economic entity such as a production sector, commodity group, household group, or government. Each nonzero cell represents a transaction and contains the payment in monetary units, possibly imputed, from the column account to the row account. Savings and changes in stocks are included as accounts, and the SAM must balance: the row total of receipts in an account must equal the column total of expenditures.

Table 1 is a small SAM. It shows the payments from three factors of production to two household groups (columns 1 to 3), payments from two composite factor inputs to the three basic factors (columns 4 and 5), household expenditure (columns 6 to 9), government expenditure (column 10), the composition of investments by sector of origin (column 11), the input-output matrix and factor inputs to production (columns 12 and 13), and the make matrix and the indirect taxes on commodities (column 14 and 15). The SAM is slightly more disaggregate than needed, but this helps in modeling. For simplicity, we have excluded foreign trade.

SAM-BASED MODELS

A SAM-based model produces, for each time period, a SAM with the same structure as the base-period SAM. It has the following variables:

- \( t_{ij} \) - The transaction value in cell \((i,j)\), i.e. the monetary value of the payment from account \(j\) to account \(i\) in current prices. We assume that only nonzero cells in the base SAM will exist in future periods.
- \( p_j \) - The price index associated with account \(j\).
- \( y_j \) - The total monetary transactions, receipts or expenditures, of account \(j\).
- \( q_j \) - The quantity index for the transactions in account \(j\).

Only a subset of the accounts will have a price index and an associated quantity index. Examples are labor (wage), capital (rent), and activities and commodities. A tax account will never have a price index. A household account need not have a price index, but it could have its own "consumer price index."

Prices, values, and quantities are related by \( y_j = p_j \cdot q_j \). Since we have chosen all price indices to be one (1) in the base period, quantity indices must be interpreted properly. One unit of labor or capital is defined as the amount of labor or capital that earned one unit of income in the base period.

The definition of a price for an account implies that the account sells a uniform product or that all transactions in the row take place at the same price. If labor in the agricultural sector differs from labor in the manufacturing sector, the SAM must have separate accounts for them.

Tables 2 and 3 give an example of a model based on the SAM in Table 1. For each of the nonzero cells in the SAM, Table 2 contains a number that defines the behavior of the cell according to the following list (abstracted for present purposes from a longer list):

2 - The cell is a residual, i.e. the value adjusts such that row and column totals become equal. This type of cell is used, for example in the government account to indicate that government savings adjust to changes in tax and other revenues and to changes in current expenditures.
The Transaction Value Approach

3 - The value of the cell is determined exogenously. This type of cell is used, for example, to define a fixed government expenditure item.

4 - The cell defines a tax payment as a fixed proportion of the pretax income in the column.

5 - The income in the column is allocated over the different rows in fixed proportions. It is here used to define how the factor incomes are paid to the household groups (i.e., in proportion to factor endowments).

6 - The cell defines a committed expenditure in a linear expenditure system, i.e., the payment for a fixed quantity of basic consumption.

11 - The cells in the column are inputs to a CES production function. In the model we have assumed that labor and capital can substitute each other.

12 - The cells in the column are inputs to a Leontief production function. Thus, columns 12 and 13 specify that the composite factor inputs from accounts 4 and 5, and the intermediate inputs, enter into production in fixed quantity ratios.

18 - The cell defines the discretionary expenditure part of a linear expenditure system. In this illustration, we have for convenience modeled the urban household savings as a discretionary expenditure.

Table 3 defines the overall behavior of each account by indicating whether p_j, y_j, and q_j are endogenous, exogenous, or undefined. In the illustration, q_2 and q_3 are exogenous to reflect a fixed amount of capital. Labor is assumed to be perfectly mobile between sectors, and the wage rate is used as a numeraire, i.e., p_1 is exogenous and total labor income is fixed relative to it. This is the same as assuming a fixed labor supply.

The following comparative statics experiment has been solved. All components of government current expenditures grow 30 percent financed by doubling the tax rate for manufacturers and halving the agricultural tax. The elasticities of substitution between labor and capital are both set of 0.5, and all other exogenous variables and parameters are kept at their base values. The solution is shown in Tables 4 and 5. Notice that the solution comes back in the same format as the base SAM, making comparisons easy.

THE TRANSACTION VALUE APPROACH TO MODELING

The idea behind the Transaction Value (TV) approach is that the modeler should only need to specify how each cell and account behave. For cells the modeler specifies the appropriate algebraic expression; for accounts, whether the y-variable is exogenous (such as a fixed government expenditure budget), or endogenous. Also to be specified is whether the account has a price and, if so, whether the price and the quantity are exogenous or endogenous. SA_MLIB will analyze the types of cells in each row and column and automatically generate appropriate balancing equations to create a complete model. Redundant equations will not be generated. If there is a choice between alternative forms of a balance equation, SA_MLIB will try to choose the best. Combinations of assumptions leading to economically inconsistent behavior within a single account are caught and reported as modeling errors.

The TV approach has been made operational by defining a menu of possible behaviors for the cells and a menu of types for the accounts. A restriction discussed in the next section has limited the number of cell types and thereby made this menu approach practical. The modeler specifies a model as a list of cell types or "TV values" and a list of account types. The cell types include:

- Input into a Production or Substitution Function. SA_MLIB can handle Leontief, Cobb-Douglas, and general CES production functions, including CES production functions with infinite elasticity corresponding to perfect substitutability. The system automatically generates price equations that connect the prices of inputs to the prices of outputs. The Cobb-Douglas specification can also describe fixed-value shares in a nonproduction column, in which case no price equation is defined.

- Expenditure Systems. There are specifications for the committed and discretionary expenditure components of a linear and a nonlinear expenditure system. The system automatically generates the appropriate consumer price indices.

- Tax Specifications. Tax payments are defined as a fixed proportion of the pretax income. The system generates price equations that adjust prices accordingly.

- Export Demand Functions. Exports depend on the price of the exportable commodity (after export taxes) relative to an exogenous world price. The exchange rate, defined as the price of the rest-of-the-
world account, can be endogenous or exogenous.

Import Specifications. The system automatically generates equations that relate world prices, tariff rates, and the exchange rate to landed prices.

Output from a Production Possibility Frontier. This specification can define fixed or price-dependent make matrices based on Leontief or CES production possibility frontiers.

Exogenous Cells. These cells can, for example, describe transfers from abroad or policy-imposed payments.

Residual Cells. These cells simply adjust to satisfy the accounting identities and in certain cases models profits.

An advantage of the TV approach and SAMLIB is the ease with which different assumptions can be plugged in. Merely by changing the type of few cells and accounts, it is possible to go from a model with exogenous investments and an endogenous current account deficit to one with fixed borrowing and endogenous investments. Assumptions about fixed or floating exchange rates, world market conditions, labor supply, and the like can also be easily changed.

MODEL ASSUMPTION

Conceptually, the behavior of a cell can depend on any other variable in the model. But to systematize the description of cells, we have restricted ourselves to behaviors in which the value of a cell \((i,j)\) only depends on \(p_i, p_j, y_i, y_j\), and parameter values. Although this restriction may sound severe, almost all practical cases can be modeled by allowing some disaggregation of the SAM's accounts.

Our model in Tables 1 to 5 contains a linear expenditure system. This is usually written as

\[
t_{ij} = \gamma_{ij} P_i + \beta_{ij} (y_j - \sum y_{ik} P_k)
\]

But we have disaggregated consumer expenditure into two accounts. The committed expenditures \(t_{ij} = \gamma_{ij} P_i\) are in the first account. Whatever is left over, \(y_j - \sum y_{ik} P_k\), becomes the total, \(y_k\), of the discretionary expenditures account via a residual cell, and the discretionary expenditures become \(t_{ik} = \beta_{ik} y_k\). The composite factor accounts (4 and 5) have also been included in the SAM for modeling purposes. In effect, they allow one to model a hierarchical production function that aggregates capital and labor in a composite factor input by using a CES production function and combine the composite factor input with the intermediates into the final output by using Leontief technology assumptions. This procedure could not be described in a single account without rather complicated expressions for the cell. But with multiple accounts, one of which is for a composite factor, the formulation is straightforward.

Such disaggregations will increase the size of the SAM and the model, making them look rather large. As compensation, the output of the model will contain all the intermediate variables. This makes it much easier to analyze and explain results and to trace any formulation errors.

The miniature ORANI model of Dixon and co-workers (1982) is an example of a model that grows significantly by such disaggregation. In their formulation, each cell in the I/O matrix and in the consumption system is a Cobb-Douglas aggregate of imports and domestically produced commodities. Since the shares in the Cobb-Douglas functions all are different, it is necessary with our approach to create a separate account for each I/O-cell and each consumption component. In most other models, imports and domestically produced commodities are aggregated into a composite commodity, independent of final use, following Armington (1969). The Armington approach is better suited to the data situation in developing countries and has the advantage of only creating one extra account per commodity group.

PARAMETER ESTIMATION AND UPDATING

The cell equations all contain parameters — such as shares, elasticities, propensities to consume — and numerical values for these parameters must be provided before the model can be solved.

Fortunately, most base-period parameters are uniquely defined once we assume that the base-period SAM is a solution to the model in the base period. Shares in production functions, base-year tax rates, and import and export parameters can all be derived from the base SAM. Base-period values of such parameters as elasticities of substitution cannot be derived from the base SAM and must be estimated from independent data sources.

Most parameters can in principle be time-dependent. But, due to a lack of data, we must often make simplifying assumptions about parameter changes. Parameters in production functions are usually kept constant, though our system has options for changing base shares and defining
efficiency parameters. Coefficients in expenditure systems are usually changed proportionally with population to reflect a constant per capita expenditure pattern.

The parameters that can be defined from the base SAM are automatically initialized by SAMLIB. From there on, the system allows many types of updates. The user defines the parameters that are time-dependent and those that are not. Those that are can be updated by specifying a new value, by specifying a growth rate, or by computing new values in an interperiod FORTRAN subroutine, possibly based on previous endogenous variables. The system checks that all parameter updates are supplied exactly once, and it checks the value of the new parameters. For example, it checks whether shares add to one and whether certain parameters are positive.

THE MODEL SOLUTION PROCEDURE

The model generation and solution procedures are long and complicated, so we will limit ourselves to a rough, intuitive description.

The first step generates the logical structure of the model. Based on the cell specifications, the account types, and the base SAM, SAMLIB defines the model: the variables and the equations, including information on the variables that appear in each equation. Each variable-equation pair is marked as invertible if the equation can be solved analytically with respect to that variable and if the resulting expression is numerically stable. If the model turns out not to be square, the solution process is stopped. Since some of the equations of the model are defined implicitly, i.e. generated by the system, it can sometimes be difficult to detect why a model is not square. We are trying to develop tools to help locate such errors.

The second step performs a block decomposition of the model and partitions the simultaneous blocks into a recursive part and a spike or loop part. This partition has been discussed by Nepomiauchy and Ravelli (1978) and Gilli and Rossier (1981). Going further than these authors, we have developed a partitioning heuristic, that, based on the invertibility information from the first step, selects the normalization of the recursive equations as an integral part of the decomposition. The algorithm is based on ideas in Hellerman and Earick (1972). This method should give a smaller number of spike variables and therefore a model that is easier to solve — rather important because many of our models have 1,500 to 2,500 equations, of which 1,200 to 2,000 are in one simultaneous block.

The third step solves the model numerically. In this brief description of the procedure we will are mainly concerned with the spike variables and equations since everything else can be substituted out numerically. The model can be thought of as

\[ \mathbf{g}(\mathbf{x}_t, \mathbf{z}_t) = \mathbf{0} \quad t = 0, 1, \ldots, T \]

where \( \mathbf{x}_t \) is the vector of unknown spike variables and \( \mathbf{z}_t \) is the vector of exogenous and lagged variables. \( \mathbf{x}_0 \) is known from the base SAM. Starting from \( \mathbf{x}_0 \) and \( \mathbf{z}_0 \), we solve the model by tracing both \( \mathbf{x}_t \) and \( \mathbf{z}_t \) continuously through time, as discussed by Garcia and Zangwill (1982). \( \mathbf{z}_t \) is moved along a straight line from \( \mathbf{z}_0 \) to \( \mathbf{z}_1 \), and the model is solved with respect to \( \mathbf{x}_t \) for each time-step using a Newton-type algorithm. This approach has several advantages over the straightforward Newton method:

- Newton's method will not always converge if the initial \( \mathbf{x}_t \) is far from a solution. But by choosing the time-step properly and using extrapolations for \( \mathbf{x}_t \) based on earlier steps, \( \mathbf{x}_t \) remain close to a solution and Newton's method converges fast.

- It becomes possible to handle domain constraints like nonnegativity for certain prices and values. Many algorithms will break down if \( \mathbf{x}_0 \) is feasible but \( \mathbf{x}_1 \) is not feasible due to inequalities. But we trace \( \mathbf{x}_t \) with time until the first infeasibility appears, thereby pinpointing the exact situation in which the price or production level becomes negative.

- The inverse Jacobian used by Newton's method is computed by numerical differences in the base period, and then updated with rank-1 modifications during the iterations as suggested by Broyden (1970), thus keeping the number of function calls small. The rank-1 modifications are similar to those used by Powell's hybrid algorithm (1970a, 1970b), which is very popular for general equilibrium models (Dervis, de Melo, and Robinson, 1982).
The procedure can be proven to converge if the model has bounded multipliers with respect to any external shock, which seems to be a fair assumption.

CONCLUSIONS AND DIRECTIONS FOR FUTURE RESEARCH

The TV approach has been developed to make it easier for users without knowledge of computer programming or solution algorithms to define, solve, and experiment with economywide equilibrium models based on SAMs. Although we have restricted the class of models, it seems that most models can be handled within the system. Our experience from a limited number of models is that our approach reduces the human input needed for building general equilibrium models. The necessary skills have also been limited to cover modeling and general economic understanding. Computer costs are difficult to compare: each simulation probably is slightly more expensive with SAMLIB, but the success rate, especially for difficult models, seems to be better than with other techniques.

Future work will, apart from general improvements in speed and reliability, cover three areas. The first is to make the system more useful for operational work by writing a "cook-book" that describes alternative TV formulations of various parts of the economy: e.g., consumption, production, trade, and investment. The second area is to systematize the formulation of interperiod linkages, thus far a rather weak aspect of the system. The third area is to expand the class of models. In this we envisage the inclusion of inequality constraints and complementarity conditions to model changes of regime and other discontinuities or nondifferentiabilities in behavior.

REFERENCES


Table 1: Example of a Social Accounting Matrix (SAM).

<table>
<thead>
<tr>
<th>Factor</th>
<th>Labor</th>
<th>Capital</th>
<th>Composit</th>
<th>Rural</th>
<th>Urban</th>
<th>Government</th>
<th>Savings</th>
<th>Activity</th>
<th>Commodity</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricult</td>
<td>60.</td>
<td>40.</td>
<td></td>
<td></td>
<td></td>
<td>90.</td>
<td>20.</td>
<td>50.</td>
<td>100.</td>
<td></td>
</tr>
<tr>
<td>Manufact</td>
<td>30.</td>
<td>50.</td>
<td></td>
<td></td>
<td></td>
<td>90.</td>
<td>40.</td>
<td>50.</td>
<td>130.</td>
<td></td>
</tr>
<tr>
<td>Agricult</td>
<td>30.</td>
<td>50.</td>
<td></td>
<td></td>
<td></td>
<td>90.</td>
<td>50.</td>
<td>50.</td>
<td>160.</td>
<td></td>
</tr>
<tr>
<td>Manufact</td>
<td>50.</td>
<td>50.</td>
<td></td>
<td></td>
<td></td>
<td>90.</td>
<td>50.</td>
<td>50.</td>
<td>160.</td>
<td></td>
</tr>
<tr>
<td>Agricult</td>
<td>60.</td>
<td>20.</td>
<td>50.</td>
<td></td>
<td></td>
<td>50.</td>
<td>50.</td>
<td>50.</td>
<td>90.</td>
<td>90.</td>
</tr>
<tr>
<td>Manufact</td>
<td>20.</td>
<td>50.</td>
<td>50.</td>
<td></td>
<td></td>
<td>50.</td>
<td>50.</td>
<td>50.</td>
<td>90.</td>
<td>90.</td>
</tr>
</tbody>
</table>

Table 2: The TV-Specification for a Model Based on the SAM in Table 1.
### Definition of Account Types:

<table>
<thead>
<tr>
<th>Factor Type</th>
<th>Labor</th>
<th>Capital</th>
<th>Manufacturing</th>
<th>Agriculture</th>
<th>Human Capital</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 FACTOR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.</td>
</tr>
<tr>
<td>2 FACTOR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.</td>
</tr>
<tr>
<td>3 FACTOR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.</td>
</tr>
<tr>
<td>4 FACTOR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.</td>
</tr>
<tr>
<td>5 FACTOR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.</td>
</tr>
<tr>
<td>6 FACTOR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.</td>
</tr>
<tr>
<td>7 FACTOR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.</td>
</tr>
<tr>
<td>8 FACTOR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.</td>
</tr>
<tr>
<td>9 FACTOR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.</td>
</tr>
<tr>
<td>10 FACTOR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.</td>
</tr>
<tr>
<td>11 FACTOR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.</td>
</tr>
<tr>
<td>12 FACTOR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.</td>
</tr>
<tr>
<td>13 FACTOR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.</td>
</tr>
<tr>
<td>14 FACTOR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.</td>
</tr>
<tr>
<td>15 FACTOR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.</td>
</tr>
<tr>
<td>16 FACTOR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100.</td>
</tr>
</tbody>
</table>

### Solution in Period 1:

<table>
<thead>
<tr>
<th>Account Type</th>
<th>Price</th>
<th>Value</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>FACTOR</td>
<td>1.0000</td>
<td>100.0</td>
<td>100.0</td>
</tr>
<tr>
<td>CAPITAL</td>
<td>1.0313</td>
<td>30.9</td>
<td>30.9</td>
</tr>
<tr>
<td>MANUFACT</td>
<td>1.0103</td>
<td>91.9</td>
<td>90.9</td>
</tr>
<tr>
<td>FACTOR</td>
<td>0.9742</td>
<td>86.8</td>
<td>89.1</td>
</tr>
<tr>
<td>FACTOR</td>
<td>0.9031</td>
<td>30.9</td>
<td>30.0</td>
</tr>
<tr>
<td>FACTOR</td>
<td>0.9539</td>
<td>47.7</td>
<td>50.0</td>
</tr>
<tr>
<td>FACTOR</td>
<td>0.9103</td>
<td>91.9</td>
<td>90.9</td>
</tr>
<tr>
<td>FACTOR</td>
<td>0.9742</td>
<td>86.8</td>
<td>89.1</td>
</tr>
<tr>
<td>FACTOR</td>
<td>1.0657</td>
<td>23.8</td>
<td>22.3</td>
</tr>
<tr>
<td>FACTOR</td>
<td>0.9126</td>
<td>47.7</td>
<td>50.0</td>
</tr>
<tr>
<td>FACTOR</td>
<td>0.9742</td>
<td>86.8</td>
<td>89.1</td>
</tr>
<tr>
<td>FACTOR</td>
<td>1.0905</td>
<td>210.4</td>
<td>193.0</td>
</tr>
</tbody>
</table>

Table 3: The Definition of Endogenous and Exogenous Variables for the Model in Table 2.

Table 4: Solution Values for the Account Dependent Variables from the Model in Table 2 and 3.


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