Maximization of National Income with Linear Programming and Input-Output Analysis: An Application for Turkey

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Abstract

The input-output and linear programming models are widely used quantitative models for economic planning. Input-output analysis deals with all goods and services produced in an economy on the basis of sectors and analyze the numerical relationship of one sector with others but is not interested in resource allocation. Linear programming model is the main method used for optimal resource allocation. It is aimed in this study to handle effectiveness planning in Turkey's economy by using input-output model and linear programming method. The main goal of this study is to specify the level of sectoral production, investment, and, imports in order to maximize national income. TurkStat's supply-use and input-output tables of 2002 are used for this purpose. These tables that show the relationship between uniformly dispersed sectors in an economy are rearranged according to the Statistical Classification of Economic Activities within the industry and product classification used in the European Community (NACE Revision 1.1) and the annual Statistical Classification of Products (CPA 2002) and reduced to 25 sectors after consolidation process. Using this consolidated table, a mathematical model is built to maximize national income and define optimum distribution of economic resources and the model is solved by linear programming method.

Keywords: Input-Output Analysis, Linear Programming, Sensitivity Analysis

Jel Codes: C02, C44, C61, C67

1. Introduction

Development movements began to be examined in economic planning methodology after World War II. The techniques used for preparation of plans diversify structurally in different countries because of various reasons such as diversity of economic and social policies adopted by the countries, difference in development level between countries and difference in statistical data qualitatively and quantitatively required for planning.

Since the input-output model that analyzes sectoral relations is a consistency model and consistency is required for, planning, input-output model is an important mathematical tool for economic planning. The input-output table generated by displaying quantitative mutual interdependence caused by industrial production, consists the basis of the input-output model. The input-output analysis is frequently used for structural analysis of economy and it leads economic decisions and decision makers so that it shows the mutual interdependence of sectors. Moreover, it is getting very important for less developed and developing countries those who need economic planning.Input-output models are known as consistency models used to determine the level of sectoral production to ensure supply-demand balance in the economy.

However, this model is not appropriate for defining the most efficient use of scarce resources in the economy. Linear programming models, known as activity planning in literature, can eliminate this handicap in two ways: either achieving the determined goals by being composed of input-output table or by defining optimum sectoral output levels. In this sense, the first application of linear programming techniques to the input-output model in the field of economics was carried out by Gass (1969).In the literature, it is possible to find studies that use the input-output models and linear programming models together. Some examples are as follow: Bozdag & Altan (1995), Nugent (1970), Blyth, C. A. & Crothall, G. A. (1965), Tominc, P., & Artenjak, J. (2002), Ryaboshlyk, V. (2006).

In general, national income is defined as the total value of produced goods and services in a given period in the economy and it is one of the most important concepts in economics. National income is of great importance as an economic indicator. The data obtained from the national income calculation provide important information about people's welfare, the structure and development of the economy and if the economy is growing or not (Acar, 1998).The main goal of this study is to specify the level of sectoral production, investment, and imports in order to maximize national income. Thus, optimum distribution of sectors which are uniformly dispersed and interacting with each other are determined considering the resources in the total economy. Therefore, the supply-use and input-output tables of 2002 prepared by TurkStat are utilized and considering NACE classification these tables are combined in an input-output table with 25 sectors in order to make it more useful and analytical. With the help of consolidated table, a linear programming model (as an effectiveness model) is set up and solved and then the results are commented. Sensitivity analyses also are included in this study.

2. Research Methods

2.1. Input-Output Model

Input-output model, first used by Leontief, emphasizes the production amount needed by each sector to meet the total final demand of any product. An industry requires outputs of other industries for production whereas outputs of an industry provide inputs for others. This situation indicates the mutual interdependence. Therefore, input-output analysis plays an important role in production plans and analyzing of the structure of an economy. Input-output model is a general equilibrium model that analyzes mutual interdependence quantitatively and with multi sectoral approach between production and consumption units in the economy. Nowadays, with the development of data collection and processing techniques, input-output model is widely used in a lot of fields. In spite of its wide use, input-output model is a consistency model. It does not suggest a solution for the optimal use of resources. Therefore, it benefits from the optimization models for the optimal use of resources. The most basic one of these is the linear programming model. Due to the maximization of national income in sectoral context is aimed to achieve in this study, a mathematical model using both linear programming and input-output model simultaneously is used to study it.

2.2. Input-Output Model and General Equilibrium Equations

The input-output (intersectoral actions) table is the starting point of the input-output model. Input-output table is a tool for explaining all goods and services produced in the economy and their intersectoral movement. A sector operating in an economy exhibits two different behaviors. The first behavior is the intermediate goods sector behavior that is manufacturing and selling the products as intermediate goods to the other sectors. The other behavior is the consumer sector behavior that demands intermediate goods from other sectors for production. These two different functions of the sectors are defined in input-output table as giving place those two times. They are shown in lines as "sectors that produce goods and services" and in columns as "sectors that use goods and services". Briefly, elements in the lines of an input-output table demonstrate the production made by a sector in a given period, and elements in the columns demonstrate the distribution of production of a sector to other sectors. A general view of the input-output table is shown in Table 1.

Terms used in Table 1:

X_{ij} : the amount of intermediate goods given jth sector by *i*ts sector (in lines), or the amount of intermediate goods received by *i*ts sector (in lines), or the amount of intermediate goods received by its sector from its sector (in columns), sector from its sector (in columns),
X_i: the amount of production of ith sector
C_i : the amount used by consumption from the production of its sector
I_i : the amount used by investment from the production of its sector
G_i : the amount used by government spending from the production of its sector
Z_i : the amount of production transferred to stock from the production of its sector
E_i: the amount for export from the production of ith sector,
Y_i : the amount of total domestic demand ($C_i + I_i + G_i + Z_i$),
M_i : the amount for import from the production of ith sector,
L_j : the amount of labor used by its sector,
K_j : the amount of capital used in sector j.

Looking at the lines of input-output model for an economy, the supply and demand balance between sectors is needed. While the sum of production and import gives the amount of supply, sum of intermediate demand, total domestic demand, and export represents the amount of demand. This equilibrium is shown as follow:

$$X_i + M_i = \sum_{j=1}^{N} X_{ij} + Y_i + E_i \tag{1}$$

Goods and services produced by one sector are used as intermediate goods by other sectors and demanded for consumption by final consumers (Yıldırım et al, 2009: 103). Looking at the columns of the model, the following equilibrium is written for the production comprised of intermediate inputs and primary inputs for any sector j:

$$X_j = \sum_{i=1}^{N} X_{ij} + L_j + K_j \tag{2}$$

2.3. Inputs Factors and Quantity Solution

For an input-output model with N sector, following equation can be written for distribution of any (Xi) sector output (Xi) among demand elements.

$$X_i = \sum_{j=1}^{N} X_{ij} + Y_i \quad (i = 1,2,\ldots\ldots,N) \tag{3}$$

Where; X_i represents the output of i sector, X_{ij} (shawn with the aggregation symbol) stands for the output amount of sector i given to sector j by sector i, demand for intermediate inputs for the sector's output, and Y_i represents the total external final demand for the sector’s output ($Y_i = C_i + G_i + I_i + E_i$).

The input amount of any sector used can only be expressed as a linear function of that sector.If prices are accepted stable, production function can be defined as:

$$X_{ij} = a_{ij} X_j \tag{4}$$

When equation (4) is substituted into equation (3)

$$X_i = \sum_{j=1}^{N} a_{ij} X_j + Y_i \tag{5}$$

The relationship in equation 4 is also valid for labor, capital, import, and export, so following equalities can be written.

$$\begin{aligned} L_j &= l_j X_j \\ K_j &= k_j X_j \\ M_i &= m_i X_i \\ I_i &= \imath_i X_i \end{aligned} \tag{6}$$

When equation (5) is taken into consideration, the following equation -written with matrix notation- is reached from the solution of input-output model.

$$X = (I - A)^{-1} Y \tag{7}$$

Where:

$X_{(N\text{x}1)}$: Production output vector,
$A_{(N\text{x}N)}$: Input coefficient matrix,
$Y_{(N\text{x}1)}$: Final external demand vector,

$(I - A)^{-1}$: Leontief inverse matrix.

$(I - A)^{-1}$ Leontief inverse matrix holds an important place in the Leontief inverse matrix input-output analysis. The elements of this matrix are defined as the multiplying coefficients and show the relationship between the production and final demand.

2.4. Linear Programming Model

A linear programming problem consists of a clear and measurable linear objective function and constraints defined as linear inequalities that limit the degree of realization (numerical values) of objective function. Basically, linear programming is a mathematical technique involving the optimal allocation of scarce resources according to the optimality criterion (Öztürk, 1997: 15).In other words, linear programming technique deals with optimization of objective function (minimum or maximum) by adhering to the variables and constraints. A standard linear programming model can be written as follow (Taha, 1987: 50).

$$Z_{max(min)} = \sum_{j=1}^{n} c_j X_j \tag{8}$$

$$\sum_{j=1}^{n} a_{ij} X_j (\leq, =, \geq)\, b_i \tag{9}$$

$$X_j \geq 0 \qquad i, j = 1, 2, \dots, n \tag{10}$$

X_j : Decision variables,

Z(x):Objective function,

c_j : Contribution coefficients of decision variables (j) in objective function,

a_{ij} : Contribution coefficient of jth decision variable in ithconstraint.

b_i : Amount of limited resources, in ther words the value at the right hand side of constraints.

2.5. Proposed Model for the National Income Maximization

One of the most important objectives of economic development planning is to maximize the national income. Inter-industry models are the models that examine numerically the inner connection between production and consumption units in the economy and used to determine the demand for intermediate goods and capital goods of industries. Today, main inter industry models implemented in many countries that apply development plans are the input-output models and linear programming models (Öney, 1987: 98). The inter-industry models are, in fact, obtained by combining sectoral assumptions of input-output model with calculation technique of linear programming.As known, the purpose of a programming problem is to maximize or minimize the function of activity level depending linear constraints. In planned development, one of the functions to be maximized is national income. First, consolidation in 2002 domestic input-output table is made for the purpose of determining decision variables i.e. sectors. The determined structure is as shown in Table 2.

Classification in Table 2 is generated based on the similarity of outputs and inputs (used). Proposed model for the maximization of national income is as follows:

$$Z_{max} = \sum_{i=1}^{n} I_i - \sum_{i=1}^{n} M_i \tag{11}$$

$$(1 + m_i)X_i - \sum_{j=1}^{n} a_{ij} X_j - I_i \geq C_i + E_i \tag{12}$$

$$\sum_{j=1}^{n} l_j X_j \leq L_0 \tag{13}$$

$$\sum_{j=1}^{n} k_j X_j \leq K_0 \tag{14}$$

$$X_j \geq 0 \quad (i, j = 1, 2, \dots, n) \tag{15}$$

It is useful to make some explanations about the objective function and constraints of the model. The purpose of the proposed model is to achieve the levels of sectoral production, investment, and imports in order to maximize national income. The objective function of the model proposed can be specified as equation (10) by the help of the equation (8). Here, c_j represents (investment-import) ratio for per X_j unit of each sector, X_j represents production level in the sector j, i.e. the decision variables of the model.Gross national product and national income = Consumption (C_i) + Investment (I_i) + Exports (E_i) - Imports (M_i). In this equation, considering the consumption and export amounts are estimated externally and adapted to the model, national income objective function at (10) can be obtained by using investment and import values from related equalities at (6).The first constraint in the model, constraint number (11), is related to supply-demand balance that is given at equity number (1) of the input-output model. This balance can be arranged and written as shown in (11) considering that total demand of a sector cannot exceed the supply which is the sum of production and imports.

The balance equation is also included in the model in addition to the restrictions related to the basic entries. One of them is labor force, that is among the scarce resources affecting the economic development and other one is capital constraint. By representing L_0 and K_0,the need for labor and capital, labor constraints and capital constraints can be written respectively as in equalities (12) and (13). Where l_j indicates the need for labor to produce one unit of commodity in sector j, and k_j is the amount of capital necessary to produce one unit of commodity in sector j.

3. Research Results

3.1. Solution of the Model

Solution of the model (created via the above description) with WinQSB package software is given in Table 3. The optimal solution shows that the value of national income that is the objective function is realized as 32174850 billion TL by producing in all sectors. the top five sectors with maximum production respectively are Other Services (X25), Construction (X22), Commerce (X24), Transport (X23), and Agriculture (X1) are sector.With the help of equalities (6), the investment and import levels corresponding to the level of sectoral production levels to maximize the national income is obtained as shown in Table 4. According to Table 4, there is no investment in Electricity, Gas, and Water Supply (X21) sectors.According to result given inTable 4, the subject to be considered is that the investment value for Electricity, Gas, and Water Supply (X21) sectors is zero. This is because there is no investment for this sector and the sector almost totally depends on imports. Investment figures for this sector may vary in a different year and with a different policy decision. The reason why some investment values are negative might be related to the raw data. In other words, it is because the capital formation by a sector occurred in one year has a negative value.

3.2. Sensitivity Analysis

In a linear programming model, it cannot be guaranteed that values of parameters to remain the same during implementation of the solution. Besides, after the model is started to be implemented, new decision variables may come up or new constraints may be needed. It is studied by sensitivity analysis how optimal solution is affected from the variations in structure and parameters of the model.As given in (10) – (13) equations, variations in the structure and parameter constraints of the model are; change in the values that stands at the right hand side of constraints (sources), change in technological coefficient matrix, and change arises from the addition of a new operation or a new constraint. The effects of these changes generated on optimal solution can be determined by the sensitivity analysis. In this sense, it is determined how sensitive the optimal solution is to the changes.

Sensitivity analyses of changes on the coefficients that constitute the objective function and on the sources that stand at the right hand side of constraints are examined in this study. As seen the solution in Table 5 and Table 6, rates of the coefficients of the objective function (investment-import) and upper and lower limit ranges of values of source changes at the right hand side of constraints are given. If changes that may take place on the coefficients of the objective function and on the resource variables at the right hand side of constraints remain in these ranges, solution will be valid. If changes remain outside of these ranges, the solution will change. In Table 6, shadow price indicates the change rate for each constraint at objective function as a result of a change at right hand side values. When the values of Residues and Surplus are examined, it is possible to say that all resource capacities except Constraint 22 and Constraint 27 are used but those two resources remain idle. When changes are analyzed in relation to the shadow price, it is seen that Constraint 22 and 27 are not active, Constraint 26 has positive effects, and other constraints have negative effects.

4. Conclusions

Utilizing scarce investment sources in an efficient way and determining significant sectors where investments to be directed primarily are very important when conducting development plans by using the input-output tables. Encouraging the investments to be made to those significant sectors by decision makers is going to provide a big contribution to the growth of other sectors directly or indirectly and then the whole economy. However, input-output models do not give enough information in case of interested in the optimal resource allocation to maximize the national income. In this case, it is useful to include a technique to the analysis -namely linear programming technique- that attempts to optimize an objective under particular limitations.Inter-industry models are also used in the countries preparing development plans.

The input-output model and linear programming model consisting the basis of inter-industry models for an objective function to maximize national income are implemented in this study.

While a certain value is reached by input-output method analysis, optimal solution is obtained by linear programming method. According to the solutions given in Table 3, the maximum production value is realized at Other Services sector (X25) while the minimum production value is realized at Tobacco sector (X5).The value of national income is found 32174850 billion TL via 2002 input-output model. Because there are too many variables and constraints in the model, sensitivity analysis could not be performed. Without a doubt, it is possible to perform further objective functions for economic development plans.

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Table 1: General Structure of an Input-Output Table

		Intermediate Demand				Total	Total Final Demand					Supply	
	Sectors	1	2	j	N	Intermediate Demand	C_i	I_i	G_i	Z_i	E_i	M_i	X_i
Intermediate Inputs	1	X_{11}	X_{12}	X_{1j}	X_{1N}								
	2	X_{21}	X_{22}	X_{2i}	X_{2N}								
	..	..	..	..	..								
	i	X_{i1}	X_{i2}	X_{ij}	X_{iN}								
	..	..	..	..	..								
	N	X_{N1}	X_{N2}	X_{Nj}	X_{NN}								
Basic Inputs	L_j												
	K_j												
	X_i												

Table 2: Classification of 2002 Input-Output by 25 Sectors

Sector No	Sector	Consolidated	Sector No	Sector	Consolidated
1	Agriculture	1-3	13	Rubber and Plastics	19
2	Mineral Extraction	4,6,7,8	14	Other Stone Based Industries	20
3	Crude Oil	5	15	Main Metal Industry	21
4	Food	9	16	Metal Products Industry	22
5	Tobacco	10	17	Dielectric Machinery	23
6	Textile and Leather	11	18	Electrical Machinery	25
7	Clothing	12,13	19	Transport vehicles	28-29
8	Wood and Furniture	14,30	20	Other Manufacturing	24,26,27,31
9	Paper	15	21	Electricity Gas Water	32,33
10	Printing	16	22	Construction	34
11	Chemical Industry	18	23	Transportation	39-41
12	Oil refinery	17	24	Commerce	35-37
			25	Other Services	38,42-59

Table 3: Optimal Solution Results

Decision	Solution Values	Unit Profit	Total	Reduced Costs	Basic Situation
X1	47977760	0,0023	110444,8	0	Basic
X2	4726508	-0,3632	-1716606	0	Basic
X3	556643,7	0,145	80716,67	0	Basic
X4	43465780	0,0127	553971,4	0	Basic
X5	2151444	0,0598	128757,4	0	Basic
X6	26728300	-0,0641	-1712857	0	Basic
X7	19944130	-0,0725	-1446209	0	Basic
X8	8172715	-0,1094	-894267	0	Basic
X9	3969966	-0,3276	-1300597	0	Basic
X10	2471169	-0,2717	-671320	0	Basic
X11	12455170	-0,2157	-2687042	0	Basic
X12	5252805	-0,6679	-3508606	0	Basic
X13	6267489	-0,3134	-1964450	0	Basic
X14	12487010	-0,1504	-1878059	0	Basic
X15	12011810	-0,2946	-3538234	0	Basic
X16	7564071	-0,077	-582766	0	Basic
X17	9895651	0,1725	1707029	0	Basic
X18	5230435	-0,0081	-42319,5	0	Basic
X19	9137517	-0,0221	-201756	0	Basic
X20	18183950	-0,1437	-2612324	0	Basic
X21	16023310	-0,1635	-2619363	0	Basic
X22	73364100	0,8187	60064590	0	Basic
X23	53156700	-0,0049	-262807	0	Basic
X24	65555640	0,0195	1275582	0	Basic
X25	1,73E+08	-0,0237	-4106655	0	Basic
Objective Function = 32174850					

Table 4: Investment and Import Quantities for Optimum Production Values

Decision Variables	Production (X)	Investment (I)	Import (M)
X1	47977760	1231072	1120635
X2	4726508	-1454394	262213,6
X3	556643,7	99003,84	18287,2
X4	43465780	2439844	1885877
X5	2151444	409344,7	280588,1
X6	26728300	2023393	3736246
X7	19944130	935093,5	2381311
X8	8172715	1415605	2309873
X9	3969966	-560388	740206,6
X10	2471169	-350050	321271,3
X11	12455170	-276528	2410509
X12	5252805	-756717	2751888
X13	6267489	-522309	1442141
X14	12487010	-816414	1061642
X15	12011810	-672958	2865276
X16	7564071	637302,9	1220071
X17	9895651	3355332	1648304
X18	5230435	938448,9	980765,9
X19	9137517	1497310	1699069
X20	18183950	-869201	1743115
X21	16023310	0	2619360
X22	73364100	64931804	4867201
X23	53156700	2214310	2477093
X24	65555640	5099927	3824369
X25	1,73E+08	902368,7	5009050

Table 5: Sensitivity Analysis for Objective Function Values

Decision Variables	Unit Costs (Profit)	Lower Limit Values	Upper Limit Values
X1	0,0023	-163,2783	0,4401
X2	-0,3632	-21,6418	1,2800
X3	0,1450	-645,0012	0,7487
X4	0,0127	-257,5054	0,5659
X5	0,0598	538865,4	0,6867
X6	-0,0641	-155,7101	0,5301
X7	-0,0725	-380,0613	0,7772
X8	-0,1094	-45,2074	0,5877
X9	-0,3276	-119,5749	0,7494
X10	-0,2717	-320,9643	0,7628
X11	-0,2157	-44,8833	0,7764
X12	-0,6679	-47,4241	0,2687
X13	-0,3134	-49,7592	0,7041
X14	-0,1504	-6,4923	0,9786
X15	-0,2946	-11,5902	0,6339
X16	-0,077	-12,4098	0,8914
X17	0,1725	-57,2785	0,8305
X18	-0,0081	-37,7952	0,7729
X19	-0,0221	-229,2159	0,5053
X20	-0,1437	-9,7887	0,4151
X21	-0,1635	-23,6736	0,3685
X22	0,8187	0,2061	M
X23	-0,0049	-13,1281	0,5799
X24	0,0195	-7,7096	0,6741
X25	-0,0237	-7,903	0,9746

Table 6: Sensitivity Analysis for Right Hand Side

Constraints	Right Hand Side Values	Lower Limit Values	Upper Limit Values	Surplus	Shadow Price
C1	23888090	-18274310	25901900	0	-0,4982
C2	48987	-2144500	27680200	0	-1,5276
C3	135312	-438993,4	4067236	0	-0,5851
C4	34990620	-4209268	39248890	0	-0,6133
C5	2293517	-1575,25	14392480	0	-0,5877
C6	14167360	-8069028	66482430	0	-0,7142
C7	19575620	12729070	63710140	0	-0,8309
C8	7346626	-2520377	77743720	0	-0,5774
C9	413529	-3678058	46357980	0	-1,045
C10	531177	-2171982	31409060	0	-0,9457
C11	5185018	-1476576	52017370	0	-0,9225
C12	1319784	-6406023	17520390	0	-0,6368
C13	1711817	-5529872	58674400	0	-0,8806
C14	1592507	-5686059	39914080	0	-1,0639
C15	2722846	-9807440	62505850	0	-0,8901
C16	1981626	-6878978	51750870	0	-0,8267
C17	7868106	-646350	55320620	0	-0,5885
C18	2778395	-3077793	54374080	0	-0,6975
C19	7565769	-2381608	14945310	0	-0,4845
C20	6617693	-2475646	93134260	0	-0,507
C21	4533085	-8378853	10415580	0	-0,6601
C22	30205310	-M	75163570	44958260	0
C23	34067180	-19091730	37469260	0	-0,5849
C24	36551490	-34002080	39938500	0	-0,6083
C25	1,22E+08	114732000	153050100	0	-1,0389
C26	91051260	81433200	91405270	0	3,2559
C27	2,11E+08	209826800	M	761990,9	0