Technology Transfer with Capital Constraints and Environmental Protections: Models and Applications to the Philippines

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Abstract

An efficient technology transfer from advanced to developing countries is explored by extending dynamic input-output optimization models. We include capital investments for the transferred technologies that affect the structural change and the welfare streams of consumption and the environmental state in the developing country. This technology transfer model is then linearized to solve larger problems. The linearized model was estimated and applied to assess the optimal technology transfer schedule from Japan to the Philippines.

1 Introduction

Developing countries in Asia are facing severe environmental problems along with their rapid economic growth. However, the transfer of advanced technologies could still potentially improve economic development and remedy the environmental problems of developing countries. Yet while the knowledge of advanced technologies could be transferred through international co-operation, its practical application requires advanced facilities and an immense capital investment. Since capital in the developing country is limited, it must be deliberately allocated to each advanced technology.

Any capital investment policy in a developing country must be consonant with the economic reproduction system. The output of an economic system, which would be influenced by the capital investment, would be either consumed or reinvested for further establishment of advanced technologies. Within this

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economic reproduction system, stream of consumption causing 'economic' well-being will be affected by consumption/investment decisions at each decision stage.

Another important concern is the technological interdependencies in a multi-industrial production system. Establishment of an advanced technology in one industry would affect the technological structure of the entire economic system which, in turn, affects the output and environmental performance in each industry. Thus, capital investments among industries must be coordinated in order to control the dynamic transition of technological structures, and achieve the desired effect in the welfare streams of consumption and environment.

We will incorporate the above-mentioned two aspects of investment planning into the well-known dynamic input-output framework, which could produce optimal economic growth in the presence of multi-industrial interdependencies. In typical dynamic input-output models, however, the technological structure is usually assumed to be constant over time. Here, we assume that the central planner of the developing economy can decide where to invest in the advanced technologies in each industry. This condition will accommodate structural change in a technology transfer model.

The objective function of the technology transfer model is the sum of the discounted present value of the well-being which is measured by the weighted value of consumption and the environmental conditions in each period. The only primary factor of production is labor, which is constrained not to exceed the exogenously given demographic forecasts. The decision variables are the consumption stream and the output stream that determine the substitution (advancement) of technology of each industrial sector which will ultimately affect the productivity and the environmental well-being, or the objective function, of the developing country.

In the next section, we will first introduce the technology transfer model by allowing investments in two available technologies in the dynamic input-output framework. Then, in section 3, by introducing some simplifying assumptions, we will reduce this model to describe it as a linear programming (LP) problem. We also extend this LP model to take environmental damage into account. In section 4, we estimate a 59-sector LP model for examining optimal technology transfer from Japan to the Philippines using available input-output data. We also conduct some empirical simulations with different discount rates as well as weights over the consumptions and the environmental conditions.

2 Technology Transfer in Dynamic Input-Output System

2.1 Dynamic Input-Output System

We start with the ordinary dynamic input-output model of n industry [2]. Let $x(t)$ be an n-vector whose ith element, $x_i(t)$, signifies the output (level of operation) of the ith industry in period t. Let $A = [a_{ij}]$ be an $n \times n$ matrix, where a_{ij} denotes the current input of the ith good used per unit of the jth good produced, including the portion used for maintaining that output level, in period t. Let $B = [b_{ij}]$ be an $n \times n$ matrix, where b_{ij} denotes the quantity of the ith good invested in the jth industry in order to increase the output of that industry by one unit. Let $c(t)$ be an n-vector whose ith element is $c_i(t)$, the final demand (such as consumption demand) of the ith good in period t. Now, the basic equilibrium relations between supply and demand for the ith good can be written as

$$x_i(t) = \sum_{j=1}^{n} a_{ij} x_j(t) + \sum_{j=1}^{n} b_{ij}[x_j(t+1) - x_j(t)] + c_i(t) \tag{1}$$

or in matrix form,

$$x(t) = Ax(t) + B[x(t+1) - x(t)] + c(t). \tag{2}$$

Here, we are assuming that capital is freely transferable from one industry to another, and that capital is fully employed so that $\sum_{j=1}^{n} b_{ij} x_j(t)$ in (1) also denotes the supply of the capital as well as its demand ($i = 1, 2, ..., n$). Equation (2) denotes the basic output equation of the dynamic input-output system. Matrices A and B are the current input coefficient matrix and the capital coefficient matrix, respectively. The primary resource constraint is that the sum of labor inputs does not exceed the exogenous supply of labor in period t. Let $a_0 = [a_{0j}]$ be a row vector of n dimension, where a_{0j} denotes the labor used per unit of the jth good produced. The required labor in ith industry will now be described as $a_{0j} x_j(t)$ and thus, the total labor requirement for the entire economy will be

$$a_0 x(t). \tag{3}$$

Let $L(t)$ denote the exogenous supply of labor in period t. The labor constraint will be written as follows.

$$a_0 x(t) \leq L(t). \tag{4}$$

The basic constraints of the planning model of the dynamic input-output system consists of (2) and (4), where $x(t)$ act as control variables, except for $x(0)$, which will be given in order to meet the initial condition. The objective function is usually the discounted present value of the consumption stream, valued by the social welfare function U with respect to the discount rate ρ and time horizon T, i.e.,

$$\max_{c(t)} \sum_{t=0}^{T} \frac{1}{(1-\rho)^t} U(c(t)). \tag{5}$$

2.2 Technology Transfer Model

We now endogenize the advanced technology establishment in the dynamical input-output system of a developing country. We use the term 'traditional' and 'advanced' to indicate the technologies of the developing country and those of the advanced country, respectively. The economic planner has the choice of investing in the advanced technologies as well as in the traditional technologies. But first, we consider what will happen when there is no investment of any kind in the dynamic input-output framework.

Let $\bar{A} = [\bar{a}_{ij}]$ denote the input coefficient matrix that excludes inputs for maintaining the output level. The balance equation (2) will now be reduced as follows:

$$x(t) = \bar{A}x(t) + c(t). \tag{6}$$

On the other hand, the existing capital (production facilities) will naturally depreciate, and thus, $x_i(t)$, will deflate, without the aid of inputs for output maintenance. Let us assume that such deflation occurs as represented by the following function $f_i(\cdot)$.

$$\begin{gathered} x_i(t+1) = f_i(x_i(t)), \\ f_i' \leq 0. \end{gathered} \tag{7}$$

We can approximate this type of function by the following combination of linear (affine) functions, using $\alpha_i > 0$ and $\beta_i > 0$ as scalar parameters designating the deflating characteristics of outputs in each industry i.

$$x_i(t+1) = \begin{cases} -\alpha_i x_i(t) + \beta_i & \text{if} \quad x_i(t) > 0 \\ 0 & \text{otherwise.} \end{cases} \tag{8}$$

Now, we will include this 'no investment' option in the dynamic input-output system, and thus, endogenize the technology substitution between traditional and advanced technologies. Let superscript 'a' and 'd' hereafter indicate parameters and variables by way of advanced and traditional technologies, respectively. The balance equation (1) in the technology transfer model will be reformulated, in terms of a linear system, by considering (6), as follows:

$$
\begin{aligned}
x_i^a(t) + x_i^d(t) = \sum_{j=1}^{n}\{g_{ij}^a(t) + g_{ij}^d(t)\} + \sum_{j=1}^{n}\{h_{ij}^a(t) + h_{ij}^d(t)\} + c_i(t) \\
g_{ij}^a(t) = \begin{cases} a_{ij}^a x_j^a(t) & \text{if} \quad x_j^a(t+1) \geq x_j^a(t) \\ \bar{a}_{ij}^a x_j^a(t) & \text{otherwise} \end{cases} \\
g_{ij}^d(t) = \begin{cases} a_{ij}^d x_j^d(t) & \text{if} \quad x_j^d(t+1) \geq x_j^d(t) \\ \bar{a}_{ij}^d x_j^d(t) & \text{otherwise} \end{cases} \\
h_{ij}^a(t) = \begin{cases} b_{ij}^a[x_j^a(t+1) - x_j^a(t)] & \text{if} \quad x_j^a(t+1) \geq x_j^a(t) \\ 0 & \text{otherwise} \end{cases} \\
h_{ij}^d(t) = \begin{cases} b_{ij}^d[x_j^d(t+1) - x_j^d(t)] & \text{if} \quad x_j^d(t+1) \geq x_j^d(t) \\ 0 & \text{otherwise.} \end{cases}
\end{aligned}
\tag{9}
$$

A dynamic input-output system with transferable technologies (9) must be accompanied by the following deflation constraints, in order to maintain linearity, using the class of functions as (8).

$$
\begin{aligned}
x_i^a(t+1) = \begin{cases} -\alpha_i^a x_i^a(t) + \beta_i^a & \text{if} \quad x_i^a(t+1) \ngeq x_i^a(t) \text{ and } x_i^a(t) > 0 \\ 0 & \text{if} \quad x_i^a(t+1) \ngeq x_i^a(t) \text{ and } x_i^a(t) \ngtr 0 \end{cases} \\
x_i^d(t+1) = \begin{cases} -\alpha_i^d x_i^d(t) + \beta_i^d & \text{if} \quad x_i^d(t+1) \ngeq x_i^d(t) \text{ and } x_i^d(t) > 0 \\ 0 & \text{if} \quad x_i^d(t+1) \ngeq x_i^d(t) \text{ and } x_i^d(t) \ngtr 0. \end{cases}
\end{aligned}
\tag{10}
$$

The labor constraint (4) will also be reduced as follows:

$$
\begin{aligned}
\sum_{j=1}^{n}\{g_{0j}^a(t) + g_{0j}^d(t)\} \leq L(t), \\
g_{0j}^a(t) = \begin{cases} a_{0j}^a x_j^a(t) & \text{if} \quad x_j^a(t+1) \geq x_j^a(t) \\ \bar{a}_{0j}^a x_j^a(t) & \text{otherwise} \end{cases} \\
g_{0j}^d(t) = \begin{cases} a_{0j}^d x_j^d(t) & \text{if} \quad x_j^d(t+1) \geq x_j^d(t) \\ \bar{a}_{0j}^d x_j^d(t) & \text{otherwise.} \end{cases}
\end{aligned}
\tag{11}
$$

Hence, the technology transfer model consists of (9), (10), and (11), with appropriate linearization of the objective function. Note that we also need $x^a(0) = 0$ and $x^b(0)$ to be given in order to meet the initial condition. This type of model including 'if, otherwise' contents will typically be interpreted as an optimization model using mixed integer linear programming (MILP) techniques.

3 Linear Programming Model with Environmental Concern

We often *a priori* know that transfer of any advanced technology will be beneficial to the developing country. Also, the developing country often completely lacks her B^d matrix. Thus, in this subsection, we consider the case when there is no investment in traditional technologies in the developing country, including investments for maintaining the output level. This will be a close approximation of the general case when two countries have similar geographical features.

By the above assumptions, we know that $x_j^a(t+1) \geq x_j^a(t)$ and $x_j^d(t+1) \ngeq x_j^d(t)$ for all j and t. Then, constraints (9) and (11) will be reduced as follows:

$$x_i^a(t) + x_i^d(t) = \sum_{j=1}^{n}\{a_{ij}^a x_j^a(t) + \bar{a}_{ij}^d x_j^d(t)\} + \sum_{j=1}^{n} b_{ij}^a[x_j^a(t+1) - x_j^a(t)] + c_i(t), \tag{12}$$

$$\sum_{j=1}^{n}\{a_{0j}^a x_j^a(t) + \bar{a}_{0j}^d x_j^d(t)\} \leq L(t). \tag{13}$$

On the other hand, $x_i^d(t)$ will become completely exogenous since they are the only variables that deflate by no investment. Moreover, we are now free from maintaining linearity of the deflation constraints including endogenous deflation such as (10). Thus, $x_i^d(t)$, including the initial condition $x_i^d(0)$, will be given exogenously so as to satisfy (7).

It is now possible to formulate this class of technology transfer model as a linear programming (LP) problem. For convenience, we rewrite (12) and (13), using matrix and vector terms.

$$x^a(t) + x^d(t) = A^a x^a(t) + \bar{A}^d x^d(t) + B^a[x^a(t+1) - x^a(t)] + c(t), \tag{14}$$

$$a_0^a x^a(t) + a_0^d x^d(t) \leq L(t). \tag{15}$$

For the purpose of application, we linearize the objective function (5). To keep the analysis as simple as possible, we employ the following linear objective function:

$$\begin{gathered}\max_{z(t)} \sum_{t=0}^{T} \frac{1}{(1+\rho)^t} z(t), \\ c_i(t) = c_i z(t), \quad \sum_{i=1}^{n} c_i = 1, \quad z(t) = \sum_{i=1}^{n} c_i(t).\end{gathered} \tag{16}$$

Note that we do not allow any substitution between different goods in each period, while allowing linear substitution between outputs of different periods, following [1]. The technology transfer model is thus described by (16), subject to (14) and (15). The exogenous variables and parameters are, $x^d(t)$, c_i, $L(t)$, A^a, $\bar{A}^d$, a_0^a, a_0^d, B^a, and $x^a(0)$, while $x^a(t)$ and $c(t)$, which indicate the optimal technology transfer and consumption policies, respectively, will be determined endogenously.

Let there be m kinds of factor of environmental burden to be investigated, including hazardous emissions and garbage. Let $E = [e_{ki}]$ be an $m \times n$ matrix, where g_{ki} denotes the kth factor of environmental burden, directly generated per unit of the ith good produced. Let $\epsilon(t) = [\sum_i^n \epsilon_{ki}(t)]$ be an m vector, where $\epsilon_{ki}(t)$ denotes the kth factor of environmental burden, directly generated by the ith industry, in period t. Now, by identifying the characteristics of the technologies adopted, we have the following identity.

$$\epsilon_{ki}(t) = e_{ki}^a x_i^a(t) + e_{ki}^d x_i^d(t) \tag{17}$$

or, in matrix form,

$$\epsilon(t) = E^a x^a(t) + E^d x^d(t). \tag{18}$$

The objective function of the technology transfer LP model must be modified so as to include environmental concern. Let $\lambda = [\lambda_k]$ be an m vector, where λ_k denotes the relative significance of the kth factor of environmental burden to the aggregated consumption level. Then, the objective function (16) will now be,

$$\max_{z(t)} \sum_{t=0}^{T} \frac{1}{(1+\rho)^t} [z(t) + \lambda \epsilon(t)]. \tag{19}$$

The LP technology transfer model with environmental concern consists of (19), (14), (15), and (18).

4 Optimal Technology Transfer from Japan to the Philippines

We developed the above-mentioned LP technology transfer model of 59 sectors using available input-output tables for the Philippines and Japan. We assume that Japan acts as the source of advanced technologies and the Philippines receives advanced technologies and substitutes them for traditional technologies.

4.1 The Database

For our empirical study we used the 59-sector input-output table of the Philippine economy in 1994, which was compiled by Secretario [3]. The A^d matrix in physical terms was estimated by using the price vector (including wage rate) of the corresponding year. Note that non-physical goods were measured using embodied labor intensity. Accordingly, we aggregated the 405-sector input-output table of the Japanese economy in 1995 [4] so as to agree with the 59 sectors of the Philippines. Matrices A^a and B^a as well as vector a_0 in physical terms were obtained by using the price vector available in [4]. For the environmental burden coefficient matrix of the Philippines E^d, we utilized the primary energy goods consumption for each sector. For those of Japan, we utilized the database developed by Hondo [5]. In the present study we only consider the environmental burden with respect to carbon emission. Further, we assume a linear deflating function of capital that will perish in 30 years.

4.2 Results

As a benchmark simulation, we first introduce the result of a 0% discount rate with no environmental concern ($\rho = 0$, $\lambda = 0$), as shown in Figure 1. In this figure, the horizontal axis corresponds to the 59 industrial sectors identified in Table 1; the vertical axis corresponds to the extent of technology transfer at period t, represented by $\log_{10} \frac{x_t}{x_0}$; and the depth corresponds to the periods. Further, the industrial sectors are sorted by the vertical values after 20 years (t =20).

As shown in Figure 1, it is evident that the top-priority industrial sectors for technology transfer are: 23 (Basic industrial chemicals), 33 (Iron and steel), 12 (Animal feeds), and 4 (Forestry). The semi-priority sectors are: 39 (Motor vehicles, parts, and accessories), 48 (Railway transport), 20 (Paper and paper products), and 36 (Machinery except electrical). That is, technology must be transferred in the basic materials industries at the early stage, followed by transfer in the manufacturing industries.

Next we investigate whether such an optimal technology transfer policy changes when ρ and λ differ. Figure 2 shows the result when we alter only the discount rate ρ to 7%. Figure 3 shows how this difference in ρ affects the technology transfer policy. In Figure 3, the vertical axis corresponds to the priorities (top to bottom) when $\rho = 0\%$, while the horizontal axis corresponds to those when $\rho = 7\%$. It is evident from this figure that little modification in the technology transfer policy is needed.

On the other hand, Figure 4 shows the result when we alter only the weight of the environmental well-being. In this case, we assume that the disutility associated to a ton increment in carbon emission is 20,000 yen ($\lambda = 20$). Here again we look at the modification in the optimum transfer policy between different parameters ($\lambda = 0$, $\rho = 0$) and ($\lambda = 20$, $\rho = 0$) as described in Figure 5. According to this figure, the priority of transfer in sector 40 (Motorcycles and bicycles) is increased, while those in 38 (Other electrical appliances), 42 (Other transport equipment), and 46 (General construction) are decreased. Clearly, the optimum transfer policy will be significantly affected by the extent of the environmental concern.

5 Concluding Remarks

In the present study, we formulated the technology transfer options for a developing economy within the dynamic input-output framework. Our technology transfer model enables us to systematically derive the optimum schedule of technology transfer in each industrial sector, through investment control in each period of the development, so as to maximize the discounted social welfare stream including environmental well being in the developing country.

A reduced model was formulated in terms of a linear programming problem, so that a larger model could be solved. We further introduced the environmental concern and regional interdependencies in this LP technology transfer model. For application purposes, we specified data availability for compiling one for the Philippines in which serious environmental protection is needed. We selected Japan for the source of advanced technologies to be transferred. The effectiveness of our model was examined using a numerical example.

References

[1] Kaneko K. (1976) *Input-Output Analysis.* Yuhikaku. (in Japanese)

[2] Takayama, A. (1994), *Mathematical economics.* Cambridge University Press.

[3] Secretario, F. T. (2000) *1994 Input-Output Accounts of the Philippines.* ARCSIGMA SCII.

[4] Management and Coordination Agency, Japan (2000) *1995 Input-Output Tables*.

[5] Hondo, H., Tonooka, Y., and Uchiyama, Y. (1997), "Environmental Burdens Associated with Production Activities in Japan using an Input-Output Table," SERC/CRIEPI Report Y87017. (in Japanese)

No.	industrial sector
1	Agricultural crops
2	Livestock and poultry
3	Fishery
4	Forestry
5	Mining
6	Meat and meat products
7	Dairy products
8	Milled rice and corn; flour; bakery products
9	Sugar; sugar confectionery
10	Fish preparations
11	Oils and fats
12	Animal feeds
13	Other food products
14	Beverages
15	Tobacco manufactures
16	Textile manufactures
17	Wearing apparel and other made-up textile goods
18	Wood and cork products
19	Furnitures and fixtures, wooden
20	Paper and paper products
21	Publishing and printing
22	Leather and leather products
23	Basic industrial chemicals
24	Fertilizers and pesticides
25	Drugs and medicines
26	Other chemical products
27	Plastic products
28	Rubber products
29	Products of petroleum and coal
30	Pottery, china and earthenwares
31	Glass and glass products
32	Other non-metallic mineral products
33	Iron and steel
34	Non-ferrous metals
35	Fabricated metal products
36	Machinery except electrical
37	Household electrical appliances
38	Other electrical machinery and apparatus
39	Motor vehicles, parts and accessories
40	Motorcycles and bicycles
41	Shipbuilding and repairing
42	Other transport equipment
43	Miscellaneous manufactures
44	Electricity, gas and steam
45	Waterworks and supply
46	General construction
47	Wholesale and retail trade
48	Railway transport
49	Road transport
50	Water transport
51	Air transport
52	Storage and other transport-related services
53	Postal and telecommunication services
54	Finance and insurance
55	Real estate
56	Ownership of dwellings
57	Hotel and restaurant services
58	Other private services
59	Government services

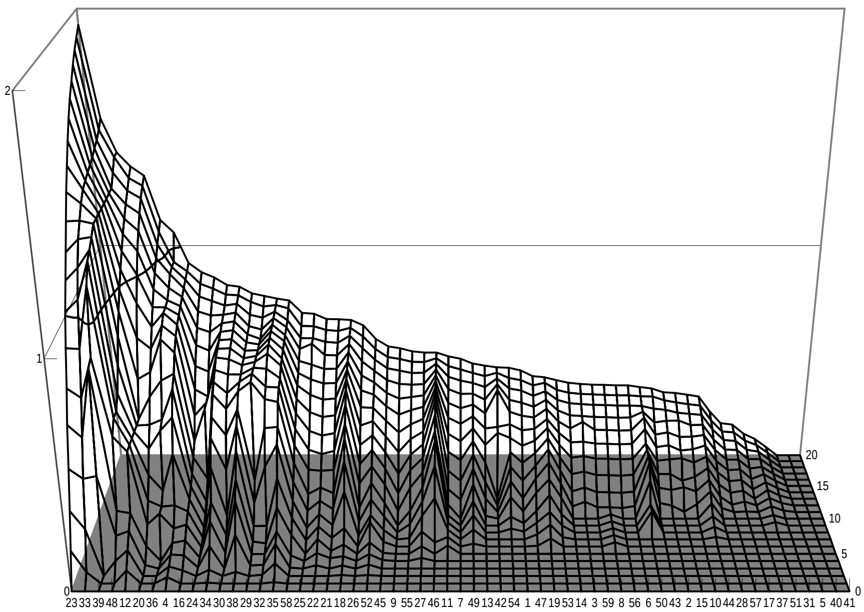

Figure 1: Optimum technology transfer policy ($\rho = 0$, $\lambda = 0$).

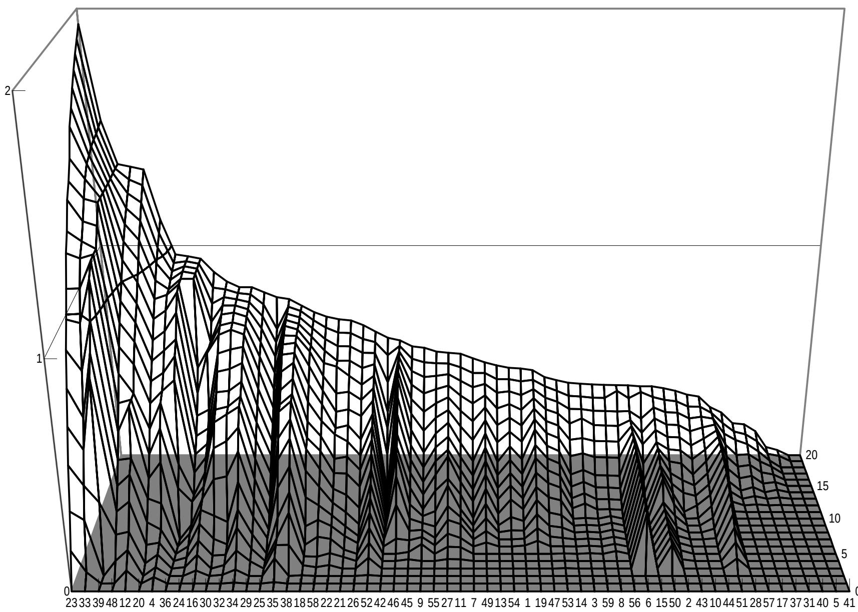

Figure 2: Optimum technology transfer policy ($\rho = 7,\ \lambda = 0$).

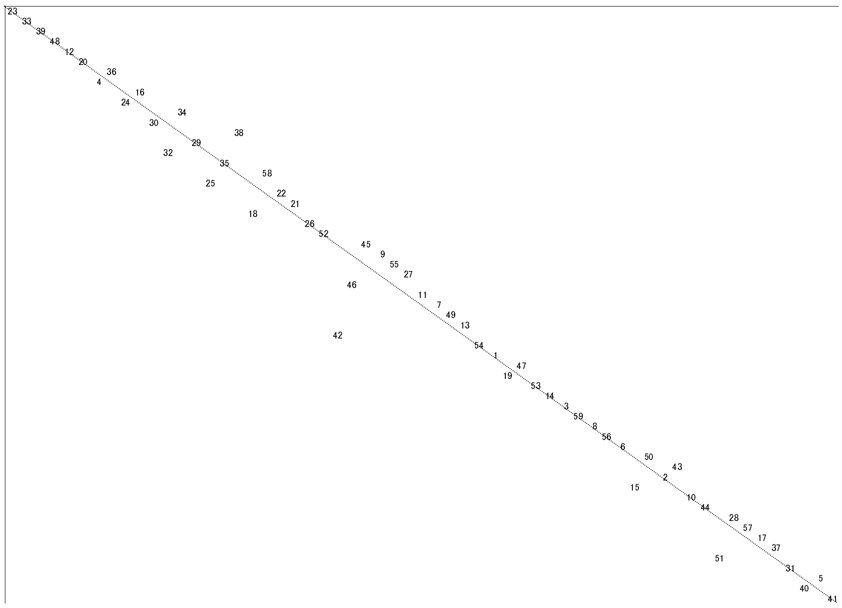

Figure 3: Sensitivity ($\rho = 0$, $\rho = 7$).

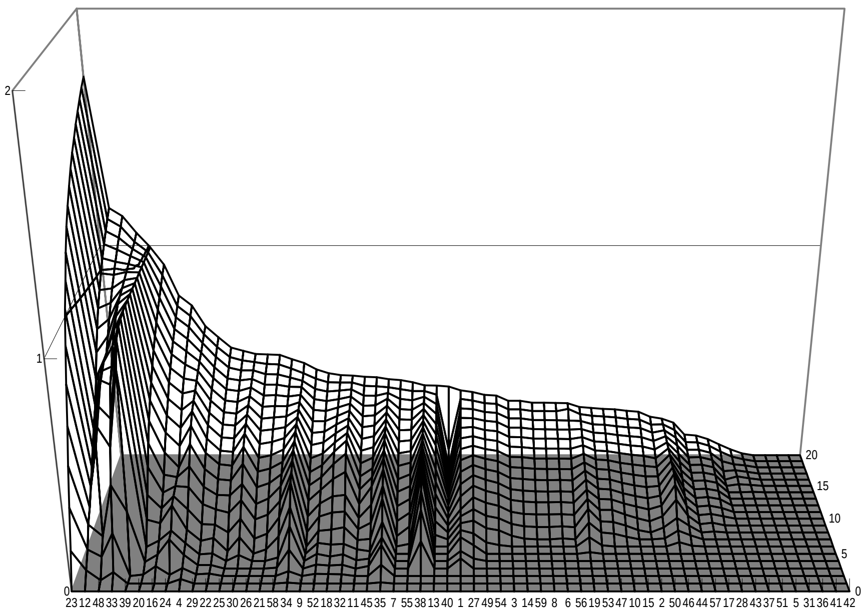

Figure 4: Optimum technology transfer policy ($\rho = 0$, $\lambda = 20$).

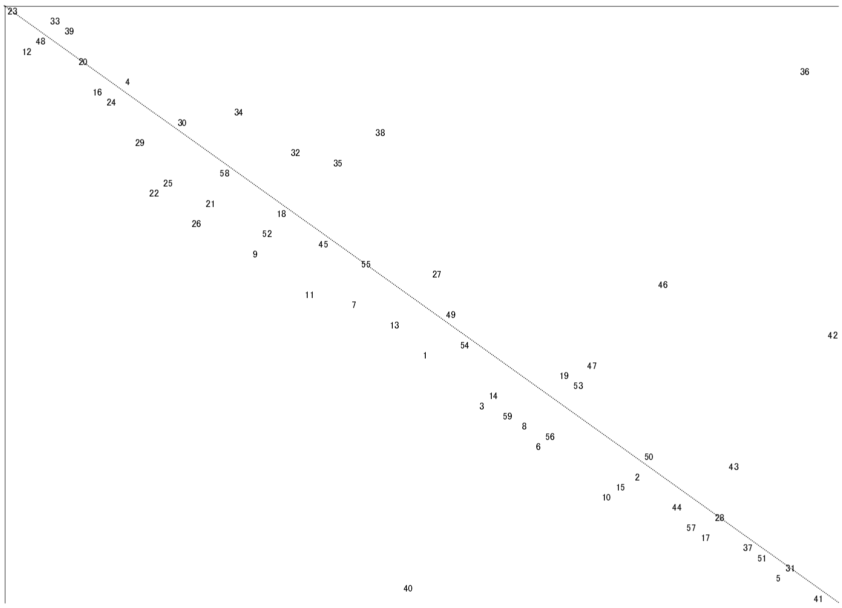

Figure 5: Sensitivity ($\lambda = 0$, $\lambda = 20$).