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iEMSs 2008: International Congress on Environmental Modelling and Software
Integrating Sciences and Information Technology for Environmental Assessment and Decision Making
4th Biennial Meeting of iEMSs, http://www.iemss.org/iemss2008/index.php?n=Main.Proceedings
M. Sànchez-Marrè, J. Béjar, J. Comas, A. Rizzoli and G. Guariso (Eds.)
International Environmental Modelling and Software Society (iEMSs), 2008

Information and Communication Technologies and the Income Distribution: A General Equilibrium Simulation

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Abstract: The special feature of the innovation in the information and communication technologies (ICTs) implies the improvement in the quality of consumption of goods and services including leisure hours, as well as the modification in the production process. The traditional analysis has emphasized solely the modification in the production process. This paper incorporates this special feature in analysing the relation between the innovation and the income distribution. It has been argued that the innovation of ICTs expands the unfairness of income distribution. In the traditional expression, this may be rephrased that the wealthy capitalist class becomes relatively better off, while the poor working class becomes relatively worse off. Assuming three social classes: the entrepreneurs, the capitalists, and the workers, this paper examines how the relative shares of these classes in the national income changes due to the innovation of ICTs. For three types of production functions: Cobb-Douglas type, CES type with negative substitution, and CES type with positive substitution, this paper conducts the comparative statics analysis by actually computing general equilibrium prices for the specified different parameters of ICTs in the production function. This paper derives the completely opposite conclusions between the CES type with negative substitution, and the one with positive substitution. Thus, it is shown by these simulations that theoretically, no definite relation holds between the innovation of ICTs and income distribution (or utility level). In order to derive the definite relation, one must examine what type of production function the economy has.
Keywords: ICT, general equilibrium, income distribution, simulation.

1. INTRODUCTION

Since the invention of computer in the 1930s, the information processing technology was mainly innovated by IBM until 1970s. AT&T was the main innovator of communication technology until 1970s. After the anti-trust lawsuits against these giant corporations, the barrier between communication and information industries, set by the US administration of justice (antitrust division), was removed in 1983 by the administration. In the 1990s, the US enjoyed the historic prosperity stemming from the fusion of information and communication technologies (ICTs). The innovation of ICTs has benefited not only the US but also the whole world. Furthermore, it has benefited not only the production and research facilities but also the general public by enriching their daily life. It has been argued, however, that the innovation of ICTs has expanded the unfairness of income distribution. In the traditional expression, this may be rephrased that the wealthy capitalist's class becomes relatively better off, while the poor working class becomes relatively worse off. The aim of this paper is to examine whether this unfairness emerges in the purely theoretical model. While in the traditional economics, the innovation was characterized by the modification of the production process: *e.g.* the shifts in the production functions, the special feature of the innovation in the ICTs implies the improvement in the quality of consumption of goods and services including leisure hours, as well as the modification of the production process. As an example of the analysis on the traditional innovation, we may refer to Fukiharu [2007a], which examined the relationship between the Green Revolution (GR), one of the innovations, and the profit. It is not certain whether the farmers' profit rises due to the GR, since it raises supply of grain, while reducing production cost. In Fukiharu [2007a] it was shown that when the production function is of CES (Constant Elasticity of Substitution) Type, the farmers' profit might fall with the assumption of positive substitution. This paper adopts the simulation approach to examine if the unfairness emerges under the assumption of different production functions.

In this paper, assuming three social classes; the entrepreneurs, the capitalists, and the workers, how the relative shares of these classes in the national income changes due to the innovation of ICTs. Following the Classicals' framework, the capitalists have capital goods and do not work, while the workers have no capital goods and earn income by providing his initial endowment of leisure for the other members. If the production function is assumed to be under constant returns to scale, the payment of rent for the capital goods and the one of the wage for the labor supply occupies the whole revenue of products. In this paper, however, the production function is assumed to be under decreasing returns to scale, following Fukiharu [2007a]. This assumption guarantees the positive profit: surplus. Thus, in this paper, the entrepreneur class exists. By computing the General Equilibrium (GE) prices, the comparative statics analysis is conducted. First, examining three cases on the assumption on the production function, how the shares of three social classes change due to the innovation of the ICTs is analyzed. Second, the utility change of three social classes due to the innovation of the ICTs is analyzed. We start with the Cobb-Douglas function case.

2. COBB-DOUGLAS PRODUCTION FUNCTION CASE I

In this paper, it is assumed that there is one (representative) firm, producing consumption good, q, utilizing the capital goods, K, and the labor input, L. In this section, the production function, $f[K, L]$, is assumed as in what follows:

$$q=f[K, L]=(c_K K)^{a1}(c_L L)^{a2} \quad a_1+a_2<1 \qquad (1\text{-}1)$$

where c_K is the level of ICTs with respect to the capital input in the production process, c_L is the level of ICTs with respect to the labour input. The improvement in this section is called the *additive type*. The production is conducted under decreasing returns to scale, so that the positive profit is guaranteed. The production function, defined in (1-1) is called Cobb-Douglas type.

2.1 The Behaviour of the Firm

The (representative) firm maximizes profit, π:

$$\max \pi=pq-rK-wL$$

where p is the price of the commodity, r is the rental price of capital goods, and w is the wage rate. By the profit maximization of the firm, the capital demand function, K_d, the labour demand function, L_d, the supply function of the consumption good, q_s, and the profit, π_0, are computed.

2.2 The Behaviour of the Workers

It is assumed that there is the (aggregate) household, who has the initial endowment of leisure hours, L_0=100, with no profit distribution from the firm. This class aims at utility maximization subject to income constraint:

$$\max u_L[x, l]=x^{c1b1}\, l^{\,c2b2} \text{ s.t. } px=w(L_0-l) \qquad (2)$$

where $u_L[x, l]$ is the worker's utility function, x is the quantity of consumption good, and l is the leisure consumption. Note that the innovation of the ICTs causes the modification of the utility function. The level of ITCs with respect to the consumption good is expressed by c_1, while the one with respect to leisure time is expressed by c_2. From the assumption of utility function as Cobb-Douglas type in (2) the demand function of consumption good, x_{dW}, and the labour supply function, L_s, are computed.

2.3 The Consumption Behaviour of Entrepreneurs

It is assumed that the (representative) entrepreneur, who receives the whole profit, owns the firm. This class aims at the utility maximization subject to the income receipt, π_0, consuming the commodity, x, and hiring a part of the workers, L, for this class, without providing itself as workers inside and outside the production process.

$$\max u_E[x, L]= x^{c1b1} L^{c2b2} \quad \text{s.t } px+wL=\pi_0 \qquad (3).$$

where $u_E[x,L]$ is the entrepreneur's utility function, x is the quantity of consumption good, and L is the consumption of workers' leisure hours. Note that the innovation of the ICTs causes the modification of the utility function in exactly the same way as in the case of household. The level of ICTs with respect to the consumption good is expressed by c_1, while the one with respect to leisure time is expressed by c_2. From the assumption of utility function as Cobb-Douglas type in (3), the entrepreneur's demand function of consumption good, x_{dE}, and the entrepreneur's demand function for labour, L_{dE}, are computed.

2.4 The Consumption Behaviour of Capitalists

It is assumed that there is the (aggregate) capitalist, who has the initial endowment of capital good, K_0=100, with no profit distribution from the firm, consuming the consumption good, x, and hiring a part of the workers, L, for this class without providing itself as workers inside and outside the production process. This class aims at the utility maximization subject to income constraint:

$$\max u_K[x, L]= x^{c1b1} L^{c2b2} \quad \text{s.t.} px+w\mathrm{L}=rK_0 \qquad (4)$$

where $u_K[x,L]$ is the capitalist's utility function. From the assumption of utility function as Cobb-Douglas type in (4), the capitalist's demand function of consumption good, x_{dK}, and the capitalist's demand function for labour, L_{dK}, are computed.

2.5 General Equilibrium

There are three markets in this model: commodity market, capital market, and the labour market. The general equilibrium analysis computes equilibrium prices, p^*, r^*, and w^*, which simultaneously equates demand supply for the three markets. Equilibrium conditions for the three markets are stipulated as in what follows.

$$x_{dW}+x_{dE}+x_{dK}=q_s \quad \text{(commodity market)} \qquad (5)$$
$$K_d=K_0 \quad \text{(capital market)} \qquad (6)$$
$$L_d+L_{dE}+L_{dK}=L_s \quad \text{(labour market)} \qquad (7)$$

Assuming w^*=1, we can compute other equilibrium prices:

$$p^*=100^{1-a1-a2}a_2^{-a2}(a_2b_1+b_2c_2/c_1)^{a2-1}c_K^{-a1}c_L^{-a2}$$
$$r^*=a_1b_1/(a_2b_1+b_2c_2/c_1) \qquad (8\text{-}1)$$

As the improvement of ICTs emerges in production part, commodity price, p^*, declines, with no effect on the rental price, r^*, as shown in (8-1). As the improvement of ICTs emerges in daily life part, p^* and r^* declines if c_2/c_1 increases, as shown in (8-1).

2.6 Income Distribution and Real Income (Utility) Changes

These improvements of ICTs cannot influence the income distribution, since we have

$w^*Ls^*/p^*qs^*= a_2,$ (9-1)
$\pi_0^*/ p^*qs^*= 1-a_1-a_2,$ (10-1)
$r^*K_0/p^*qs^*=a_1.$ (11-1)

The collection of (9-1)~(11-1) is a classical one. The income distribution change is one way of evaluating the economic situation of each class. In this subsection, we examine how the real incomes for the three classes change when the improvements of ICTs emerge. The utility change for each class may be another way of evaluating the economic situation of each class. In order to do this, suppose that

$a_1=a_2=b_1=b_2=1/3$ (12-1)

By the improvement of ITCs in the production part: c_K and c_L, raises the utility levels of all the class. For example, when $c_1=c_2=1$, the utility level of the workers' class increases from 7.67671 to

$7.67671 c_K^{1/9} c_L^{1/9}$ (13-1)

as c_K and c_L change from 1. When $c_1=c_2=1$, the utility level of the entrepreneur's class increases from 3.0465 to

$3.0465\, c_K^{1/9} c_L^{1/9}$ (13-2)

as c_K and c_L change from 1. When $c_1=c_2=1$, the utility level of the capitalist' class increases from 3.0465 to

$3.0465\, c_K^{1/9} c_L^{1/9}$ (13-3)

as c_K and c_L change from 1. From the simulation we can show that by the improvement of ICTs in the daily life part: c_1 and c_2, raises the utility levels of all the class.
A remark is in order. As shown in (8), p^* declines if c_2/c_1 increases. We can show that the profit also declines in this case, since $\pi_0^*=100c_1/(c_1+3c_2)\}$ holds when $c_K=c_L=1$.

3. COBB-DOUGLAS PRODUCTION FUNCTION CASE II

In this section, the production function, $f[K, L]$, is assumed as in what follows:

$q=f[K, L]=K^{cka1} L^{cla2} \quad c_k a_1+ c_l a_2<1$ (1-2)

where c_k is the level of ICTs with respect to the capital input in the production process, c_l is the level of ICTs with respect to the labour input. The improvement in this section is called the *structural type*. The production is conducted under decreasing returns to scale, so that the positive profit is guaranteed. These improvements of ICTs can influence the income distribution, since we have

$w^*Ls^*/p^*qs^*= c_l a_2,$ (9-2)
$\pi_0^*/ p^*qs^*= 1- c_k a_1- c_l a_2,$ (10-2)
$r^*K_0/p^*qs^*= c_k a_1.$ (11-2)

When the innovation of ICTs improves the efficiency in production, it raises the shares in national income, as is clear from (9-2) and (11-2). This, however, reduces the share of the profit in national income. In this situation, we examine the utility change, starting from the case of workers class. In addition to (12-1), it is assumed

$c_1=c_2=c_k=c_l=1.$ (12-2)

The utility level of the workers class, u_{L0}, and the one of capitalists class, u_{K0}, are 7.67671 and 3.0465, respectively at GE when (12-1) and (12-2) are assumed. If c_l rises to 5/4, then the share of the workers rises as shown in (9-2). In this case, not only the utility level of the workers' class but also the one of the capitalists class rise to u_{L1}=8.76165 and u_{K1}=3.33934, respectively. The results for each improvement of ICTs are summarized in Table 1.

As shown in Table 1 workers and capitalists become better off by any improvement of ICTs. If c_l rises to 5/4, then the share of the entrepreneurs falls as shown in (10-2). The utility level of this class, u_{E0}, is 3.0465 at GE when (12-1) and (12-2) are assumed. If c_l rises to 5/4, then the utility level of this class, u_{E1} falls to u_{E1}= 2.75656. This is due to the declined profit from π_{00}=25 to π_{01}=17.6471. The effects for each improvement of ICTs on the utility level and profit are summarized in Table 2. Note that as shown in Table 2, when c_2 rises to 5/4, then the utility level of the entrepreneur's class rises in spite of the declined profit.

	u_{L0}= 7.67671	u_{K0}= 3.0465
c_1=5/4	u_{L1}= 8.85721	u_{K1}= 3.53743
c_2=5/4	u_{L1}= 11.1008	u_{K1}= 3.45013
c_k=5/4	u_{L1}= 8.7243	u_{K1}= 4.01758
c_l=5/4	u_{L1}= 8.76165	u_{K1}= 3.33934

Table 1.Utility Changes for Workers and Capitalists: Cobb-Douglas Case

	u_{E0}=3.0465	π_{00}= 25
c_1=5/4	u_{E1}= 3.53743	π_{01}= 29.4118
c_2=5/4	u_{E1}= 3.45013	π_{01}= 21.0526
c_k=5/4	u_{E1}= 2.85802	π_{01}= 18.75
c_l=5/4	u_{E1}= 2.75656	π_{01}= 17.6471

Table 2. Utility and Profit Changes for Entrepreneurs: Cobb-Douglas Case

4. CONSTANT ELASTICITY OF SUBSTITUTION (CES) PRODUCTION FUNCTION CASE I: NEGATIVE PARAMETER

In this section, the CES type production function is assumed as in what follows:

$$q=f[K, L]=((c_K K)^{-t}+(c_L L)^{-t})^{-n/t} \quad n=1/2,\ t=-1/2 \qquad (1\text{-}3)$$

where c_K is the level of ICTs with respect to the capital input in the production process, and c_L is the level of ICTs with respect to the labour input. It is assumed that the production is conducted under decreasing returns to scale, so that the positive profit is guaranteed, as in the previous sections.

With the sole modification of production function, the general equilibrium prices, p^*, r^*, and w^*, are computed by solving (5), (6), (7). It is not easy to compute these prices with such a plain expression as in (8-1) when no specification of parameters is made. Thus, suppose that

$$c_1=c_2=c_K=c_L=1. \qquad (12\text{-}3)$$

When (12-3) is satisfied, we can compute equilibrium prices:

$$p^*=20/3,\ r^*=1/3. \qquad (8\text{-}2)$$

It is easy to ascertain that this equilibrium is a stable one, by computing the eigenvalues of the Jacobian matrix. The *negative* eigenvalues are derived as {–601.504, –1.49625}. The Walrasian tatonnement process is defined by the following differential equations.

$$dp[\tau]/d\tau= x_{dW}[\tau]+x_{dE}[\tau]+x_{dK}[\tau]-q_s[\tau]$$
$$dr[\tau]/d\tau=K_d[\tau]-K_0$$

where τ stands for time. The price trajectories on the Walrasian tatonnement process, starting from $p[0]$=1 and $r[0]$=1, are provided by Figure 1 and Figure 2.

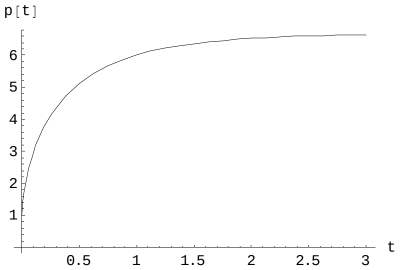

Figure 1. Price Trajectory of $p[\tau]$

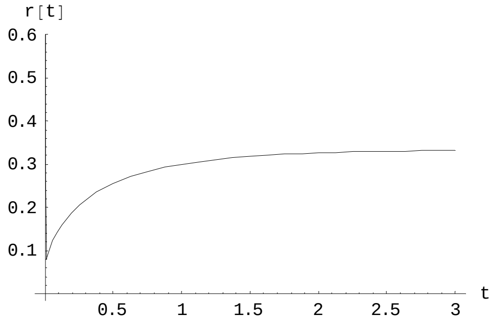

Figure 2: Price Trajectory of $r[\tau]$

4.1 Income Distribution

With no specification such as in (12-3), we can compute the income distributions, w^*Ls^*/p^*qs^*, π_0^*/p^*qs^*, and r^*K_0/p^*qs^*, as in what follows.

$$w^*Ls^*/p^*qs^*=[-c_2c_K+\{c_K(c_2^2c_K+c_1^2c_L+2c_1c_2c_L)\}^{1/2}]/2[c_1c_K+c_2c_K+\{c_K(c_2^2c_K+c_1^2c_L+2c_1c_2c_L)\}^{1/2}], \quad (9\text{-}3)$$
$$\pi_0^*/p^*qs^*=1/2, \quad (10\text{-}3)$$
$$r^*K_0/p^*qs^*=(c_1+2c_2)c_K/2[c_1c_K+c_2c_K+\{c_K(c_2^2c_K+c_1^2c_L+2c_1c_2c_L)\}^{1/2}]. \quad (11\text{-}3)$$

First, from these computations, the following holds.

w^*Ls^*/p^*qs^* rises as c_L rises, (9-3A)
r^*K_0/p^*qs^* falls as c_L rises. (11-3A)
w^*Ls^*/p^*qs^* falls as c_K rises, (9-3B)
r^*K_0/p^*qs^* rises as c_K rises. (11-3B)

Note that (9-3A) corresponds with (9-2), while (11-3B) corresponds with (11-2).
Next, with respect to the effect of c_1 and c_2 on the income distribution, we must assume that

$$c_K=c_L=1. \quad (12\text{-}4)$$

When (12-4) is satisfied, the following holds.

w^*Ls^*/p^*qs^* rises as c_1 rises, (13-1)
r^*K_0/p^*qs^* falls as c_1 rises. (14-1)
w^*Ls^*/p^*qs^* falls as c_2 rises, (15-1)
r^*K_0/p^*qs^* rises as c_2 rises. (16-1)

4.2 Real Income (Utility) Change

Following the previous analysis, the simulation analysis of utility change through the innovation of ICT is conducted. Starting from (12-3), the utility of the workers' class is computed as u_{L0}=7.21125. When c_1 rises to 5/4, the utility rises to u_{L1}= 8.07332. The utility changes for the workers' and capitalists' classes through the innovation of ICTs are summarized in Table3.

	u_{L0}= 7.21125	u_{K0}= 3.46681
c_1=5/4	u_{L1}= 8.07332	u_{K1}= 3.94296
c_2=5/4	u_{L1}=10.5663	u_{K1}= 4.12924
c_K=5/4	u_{L1}=7.35236	u_{K1}=3.66283
c_L=5/4	u_{L1}=7.35226	u_{K1}= 3.40032

Table 3. Utility Changes for Workers and Capitalists: CES Case I

	u_{E0}=4.19974	π_{00}=44.4444
c_1=5/4	u_{E1}=5.03291	π_{01}=53.2544
c_2=5/4	u_{E1}=4.98573	π_{01}=36.7347
c_K=5/4	u_{E1}= 4.321	π_{01}=45.0543
c_L=5/4	u_{E1}=4.24148	π_{01}= 43.8173

Table 4. Utility and Profit Changes for Entrepreneurs: CES Case I

Note that as c_K rises r^*K_0/p^*qs^* falls, as shown in (11-3A), while the utility rises in this parameter change, as shown in Table3. Furthermore, as c_L rises, r^*K_0/p^*qs^* falls as shown in (9-3B), while the utility falls in this parameter change. Thus, symmetry is not guaranteed in this result.

The utility and profit changes for the entrepreneurs are summarized in Table 4. As shown in (10-3) the profit share of entrepreneurs' class is 1/2. The profit itself, however, falls when c_2 or c_L rises as shown in Table 4. The consequent price decline to maintain the profit share at 1/2 raises the utility level in these parameter changes as shown in Table 4. Thus, for all the parameter changes the utility of the entrepreneurs' class rises, as shown in Table 4.

5. CONSTANT ELASTICITY OF SUBSTITUTION (CES) PRODUCTION FUNCTION CASE II: POSITIVE PARAMETER

The aim of this section is to examine whether (9-3A), (11-3A), (9-3B), and (11-3B) hold when the parameter changes from t=–1/2 to t=1/2. When t=1/2, however, the computation of GE is not easy. Thus, the Newton method is utilized in the computation of general equilibrium, and the comparison is made between the case for (12-3) and the cases in which (a) only c_1 rises, (b) only c_2 rises, (c) only c_K rises, (d) only c_L rises from (12-3). We start from the computation of general equilibrium.

When (12-3) is satisfied, we can compute equilibrium prices by the Newton method:

$$p^*=22.5,\ r^*=0.125. \qquad (8\text{-}3)$$

It is easy to ascertain that this equilibrium is a stable one, by computing the eigenvalues of the Jacobian matrix. The *negative* eigenvalues are derived as {–888.978, –0.13332}. We cannot conduct a graphical simulation of this stability due to the slow convergence.

5.1 Income Distribution

First, from the simulation in terms of the Newton method, the following holds.

w^*Ls^*/p^*qs^* falls from 0.333333 to 0.322185 as c_L rises, (9-4A)
r^*K_0/p^*qs^* rises from 0.166667 to 0.177815 as c_L rises. (11-4A)
w^*Ls^*/p^*qs^* rises from 0.333333 to 0.344208 as c_K rises, (9-4B)
r^*K_0/p^*qs^* falls from 0.166667 to 0.155792 as c_K rises. (11-4B)

Note that (9-4A)~(11-4B) are opposite to (9-3A) ~ (11-3B).

Next, with respect to the effect of c_1 and c_2 on the income distribution, the following holds.

w^*Ls^*/p^*qs^* falls from 0.333333 to 0.325184 as c_1 rises, (13-2)
r^*K_0/p^*qs^* rises from 0.166667 to 0.174816 as c_1 rises, (14-2)
w^*Ls^*/p^*qs^* rises from 0.333333 to 0.341688 as c_2 rises, (15-2)
r^*K_0/p^*qs^* falls from 0.166667 to 0.158312 as c_2 rises. (16-2)

Note that (13-2)~(16-2) are completely opposite to (13-1) ~ (16-1).

	u_{L0}=4.8075	u_{K0}=1.20187
c_1=5/4	u_{L1}=4.90633	u_{K1}= 1.21416
c_2=5/4	u_{L1}=6.97766	u_{K1}=1.23581
c_K=5/4	u_{L1}=4.89191	u_{K1}=1.16287
c_l=5/4	u_{L1}=4.89865	u_{K1}=1.28586

Table 5. Utility Changes for Workers and Capitalists: CES Case II

	u_{E0}=2.5	π_{00}=37.5
c_1=5/4	u_{E1}=2.67034	π_{01}=53.2544
c_2=5/4	u_{E1}=2.92782	π_{01}=31.4132
c_K=5/4	u_{E1}= 2.53016	π_{01}=37.1966
c_L=5/4	u_{E1}=2.5617	π_{01}= 37.8162

Table 6. Utility and Profit Changes for Entrepreneurs: CES Case II

5.2 Real Income (Utility) Change

The utility changes for the workers' and capitalists' classes through the innovation of ICTs are summarized in Table5. The tendency of rise and fall in Table 3 and Table 5 is not the

same.
The utility and profit changes for the entrepreneurs are summarized in Table 6. The tendency of rise and fall in Table 4 and Table 6 is not the same.

6. CONCLUSIONS

This paper examined the effects of four elements in innovation on the income distribution. Traditional elements in the innovation argument were restricted on the production process. In this paper, the production function has two factors of production: labour input and capital input. Thus, in this paper, the 1st element is the efficiency improvement of the labour input through ICTs, and the 2nd element the one of capital input. The special feature of ICTs consists in the fact that quality of life improves through ICTs. Thus, in this paper, since the utility function has two variables: consumption good and leisure hours, the 3rd element is the improvement of the quality of consumption good through ICTs, and the 4th is the one of leisure hours through ICTs.
In Section 1, the production function is specified by Cobb-Douglas type where the efficiency improvement implies the *additive type* as in the traditional argument: *i.e.* one unit of input becomes c unit (c>1) after the innovation. Under this assumption, the innovation of ICTs cannot change the income distribution at all. When measured in terms of utility change, however, every element contributes to the enhancement of utility for all the social classes. It was shown that the profit declines due to the 4th element.
In Section 2, the production function is specified by Cobb-Douglas type where the efficiency improvement implies the *structural type* in the sense that the improvement implies the increased parameter of the Cobb-Douglas production function. It was shown that the 3rd and 4th elements have no effect on the income distribution structure. The 1st and 2nd elements can influence the income distribution structure. When measured in terms of utility change, the workers' class and the capitalists' class become better of due to any element. It was shown that the utility of entrepreneurs' class declines due to the first or second element. In this case, the profit was also shown to decline.
In Section 3, the production function was specified by CES type with negative substitution parameter. It was shown that all the four elements influence the income distribution structure, while the income share of the entrepreneurs is constant. For example, first, the 1st element contributes to the rise of workers' income share, while the 2nd element contributes to the rise of capitalists' income share. Second, the 3rd element contributes to the rise of workers' income share, while the 4th element contributes to the rise of capitalists' income share. As for the utility change, except for the 3rd element, all the social classes become better off. The 3rd element reduces the utility of capitalists' class. It was shown that the profit falls due to the 1st or 3rd element.
In Section 4, the production function was specified by CES type with positive substitution parameter. It was shown that all the four elements influence the income distribution structure, while the income share of the entrepreneurs is constant. The results, however, completely contradict those in the previous section. It was shown that the profit falls due to the 2nd or 4th element.
The local stability was guaranteed for CES type production functions. Thus, it was shown by these simulations, that theoretically, no definite relation holds between the innovation of ICTs and income distribution (or utility level). In order to derive the definite relation, one must examine what type of production function the economy has.

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