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Information and communication technologies and the income distribution: A simulation through inequality measures

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Abstract: Since the invention of computer in the 1930s, the information processing technology was mainly innovated by IBM until 1970s, while AT&T was the main innovator of communication technology in those days. 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, and the world enjoyed the historic prosperity stemming from the fusion of information and communication technologies (ICTs). Furthermore, it has benefited not only the production and research facilities but also the general public by enriching their daily life. Thus, in this paper, 4 types of ICT innovation emerge: 2 types (elements) in the production functions, and 2 types (elements) in the utility functions. 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 main aim of this paper is to examine whether this unfairness expansion emerges in the purely theoretical model.

First, assuming three social classes; the entrepreneurs, the capitalists, and the workers, the present paper shows how the relative shares of these classes in the national income changes due to the ICT innovation. 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. In this paper, the production function is assumed to be under decreasing returns to scale, following Fukiharu [2007]. 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. Second, utilizing the unfairness measures, such as Gini coefficient and Atkinson (inequality) index, we examine if the unfairness expansion emerges due to the ICT innovation.

In Section 2, the production function is specified by Cobb-Douglas type where the efficiency improvement implies the *additive type* as in the traditional argument. Under this assumption, the ICT innovation cannot change the income distribution at all. When measured in terms of Gini coefficient and Atkinson index, there is no change in income inequality before and after the ICT innovation. In Section 3, the production function is specified by Cobb-Douglas type where the efficiency improvement implies the *structural type*. 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 Gini coefficient and Atkinson index, change in income inequality crucially depends on the parameters other than those of the four elements. In Section 4, the production function is 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. As for the change in income inequality, inequality expands when the 2nd element and/or the 4th element improve, while inequality declines when the 1st and/or the 3rd element improve. In Section 5, the production function is 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, are completely opposite to those in the previous section. Meanwhile, the same conclusion holds with respect to the change in income inequality. Thus, it was shown by these simulations that theoretically, no definite relation holds between the ICT innovation and income distribution and its inequality. In order to derive the definite relation, one must examine what type of production function the economy has.

Keywords: *General Equilibrium, ICT, innovation, Gini coefficient, Atkinson index*

1. Introduction

In the traditional economics, the innovation was characterized by the modification in the production process: *e.g.* the shifts in the production functions. This paper focuses on the innovation in information and communication technologies (ICTs). 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 in the production process. As an example of the analysis on the traditional innovation, we may refer to Fukiharu [2007], 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 [2007] 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 parameter.

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's class becomes relatively better off, while the poor working class becomes relatively worse off. 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 [2007]. This assumption guarantees the positive profit: surplus. Thus, in this paper, the entrepreneur's 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, its effect on the income inequality is examined in terms of Gini coefficient or Atkinson (inequality) index approaches. This analysis is an extension of Fukiharu [2008], which examined the utility change of three classes, stemming from the innovation of ICTs. 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 good, 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 labor 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 Agents

The (representative) firm maximizes profit, π: max $\pi=pq-rK-wL$, where p is the price of the consumption good, r is the rental price of capital good, and w is the wage rate. By the profit maximization of the firm, the capital demand function, K_d, the labor demand function, L_d, the supply function of the consumption good, q_s, and the profit, π_0, are computed.

The first agent (consumer) 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 $u_L[x, l]=x^{c1b1} l^{c2b2}$ s.t. $px=w(L_0-l)$ 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 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 the demand function of consumption good, x_{dW}, and the labor supply function, L_s, are computed.

The second consumer 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 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. max $u_E[x, L]= x^{c1b1} L^{c2b2}$ s.t $px+wL=\pi_0$ 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, the entrepreneur's demand function of consumption good, x_{dE}, and the entrepreneur's demand function for labour, L_{dE}, are computed.

Finally, the third consumer 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 $u_K[x, L]= x^{c1b1} L^{c2b2}$ s.t.$px+w$L$=rK_0$ where $u_K[x,L]$ is the capitalist's utility function. From the assumption of utility function as Cobb-Douglas type, the capitalist's demand function of consumption good, x_{dK}, and the capitalist's demand function for labour, L_{dK}, are computed.

2.2 General Equilibrium

There are three markets in this model: commodity market, capital market, and the labor 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.

$x_{dW}+x_{dE}+x_{dK}=q_s$ (commodity market) (2)
$K_d=K_0$ (capital market) (3)
$L_d+L_{dE}+L_{dK}=L_s$ (labour market) (4)

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

$$p^*=100^{1-a1-a2}a_2^{-a2}(a_2b_1+b_2c_2/c_1)^{a2-1}c_K^{-a1}c_L^{-a2}$$

$$r^*=a_1b_1/(a_2b_1+b_2c_2/c_1) \quad (5\text{-}1)$$

As the improvement of ICTs emerges in production part, commodity price, p^*, declines, with no effect on the rental price, r^*, as shown in (5-1). As the improvement of ICTs emerges in daily life part, p^* and r^* declines if c_2/c_1 increases, as shown in (5-1).

2.3 Relative Income Share and Income Distribution Inequality

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

$w^*Ls^*/p^*qs^*= a_2$, (6-1)
$\pi_0^*/ p^*qs^*= 1-a_1-a_2$, (7-1)
$r^*K_0/p^*qs^*=a_1$. (8-1)

The collection of (9-1)~(11-1) is a classical one.

Next, we examine how the inequality of income distribution changes due to the improvements of ICTs. One of the inequality measures is the Gini coefficient. For the numerically ordered income distribution of m members in a society, $\{y_1, y_2, \ldots, y_m\}$, the Gini coefficient is defined by

$$G=1+1/m-2(y_1+2y_2+\ldots+my_m)/(m^2\hat{y}) \quad (9\text{-}1)$$

where $\hat{y}$ is the mean of $\{y_1, y_2, \ldots, y_m\}$. When G becomes greater, the income distribution becomes more unequal by this approach.

In order to compute the Gini coefficient, let us suppose, for example, that

$$c_1=1, c_2=1, c_L=1, c_K=1, a_1=1/3, a_2=1/2, b_1=1/5, b_2=1/3. \quad (10\text{-}1)$$

Then, Gini coefficient for $\{w^*Ls^*, \pi_0^*, r^*K_0\}$, G_0, is 2/9. When, c_i rises due to the ICT innovation, the new Gini coefficient, G_1, remains the same. Thus, there is no inequality change. This result is self-explanatory due to (9-1)~(11-1). Another inequality measure is Atkinson (inequality) index, I_A, is defined by

$$I_A=1-(\Sigma y_i^{\alpha}/m)^{1/\alpha}/\hat{y} \quad (9\text{-}2)$$

where summation is over i=1, …, m, and α is a parameter, $\alpha<1$, $\alpha\neq 0$. As α becomes smaller, the society becomes more egalitarian. When (10-1) is assumed, the Atkinson (inequality) index, I_A^0, is 0.441994 when $\alpha=-10$, 0.0603296 when $\alpha=1/3$, and 0.00797706 when $\alpha=10/11$. As expected, when, c_i rises due to the ICT innovation, I_A remains the same. Thus, there is no inequality change.

3. COBB-DOUGLAS PRODUCTION FUNCTION CASE II

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

$q=f[K, L]=K^{c_k a_1} L^{c_l a_2} \quad c_k a_1 + c_l a_2 < 1$ (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 labor 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

$w^*Ls^*/p^*qs^* = c_l a_2,$ (6-2)

$\pi_0^*/ p^*qs^* = 1 - c_k a_1 - c_l a_2,$ (7-2)

$r^*K_0/p^*qs^* = c_k a_1.$ (8-2)

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.

Next, we examine how the inequality of income distribution changes due to the improvements of ICTs. In order to compute the Gini coefficient for $\{w^*Ls^*, \pi_0^*, r^*K_0\}$, let us suppose, for example, that

$a_1=1/3, a_2=1/3, b_1=1/2, b_2=1/3.$ (10-2)

Under (10-2) $G_0=0$ when$c_1=1$, $c_2=1$, $c_L=1$, $c_K=1$. When, c_i rises due to the ICT innovation, say c_L to 12/10, the new Gini coefficient, G_1, becomes 0.0888889. Thus, by the ICT innovation the income distribution becomes more unequal. This result crucially depends on the parameters. In order to show this, suppose that the following holds.

$a_1=1/4, a_2=1/3, b_1=1/2, b_2=1/3.$ (10-3)

Under (10-3) $G_0=0.111111$ when$c_1=1$, $c_2=1$, $c_L=1$, $c_K=1$. When, c_i rises due to the ICT innovation, say c_L to 12/10, the new Gini coefficient, G_1, becomes 0.1. Thus, by the ICT innovation the income distribution becomes more equal. In other words, the conclusion of equality depends on the parameters other than those of ICT innovation.

When (10.2) is assumed, I_A^0 for $c_L=1$ is smaller than I_A^1 for $c_L=1.2$ as shown in Table 1, thus by the ICT innovation the income distribution becomes more unequal.

α	$I_A^0(c_L=1)$	$I_A^1(c_L=1.2)$
–10	0	0.117534
1/3	0	0.00899655
10/11	0	0.00122143

Table 1: I_A when (10.2) is assumed

α	$I_A^0(c_L=1)$	$I_A^1(c_L=1.2)$
–10	0.167956	0.166478
1/3	0.014155	0.0123337
10/11	0.00191689	0.00164958

Table 2: I_A when (10.3) is assumed

Meanwhile, when (10.3) is assumed, I_A^0 for $c_L=1$ is greater than I_A^1 for $c_L=1.2$ as shown in Table 2, thus by the ICT innovation the income distribution becomes more equal. Using Atkinson index, we have the same conclusion as in the Gini coefficient: *i.e.* the conclusion of equality depends on the parameters other than those of ICT innovation.

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:

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

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 (2), (3), (4). It is not easy to compute these prices with such a plain expression as in (5-1) when no specification of parameters is made. Thus, suppose that

c_1=c_2=c_K=c_L=1. (10-4)

When (12-4) is satisfied, we can compute equilibrium prices:

p*=20/3, r*=1/3. (5-2)

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}.

4.1 Relative Income Distribution

With no specification such as in (10-4), we can compute the income distributions, $w*Ls*/p*qs*$, $\pi_0*/p*qs*$, and $r*K_0/p*qs*$, as in what follows.

$$w*Ls*/p*qs*=[-c_2c_K+\{c_K(c_2^2c_K+c_1^2c_L+2c_1c_2c_L)\}^{1/2}]/2[c_1c_K+c_2c_K+\{c_K(c_2^2c_K+c_1^2c_L+2c_1c_2c_L)\}^{1/2}], \quad (6\text{-}3)$$

$$\pi_0*/p*qs*=1/2, \quad (7\text{-}3)$$

$$r*K_0/p*qs*=(c_1+2c_2)c_K/2[c_1c_K+c_2c_K+\{c_K(c_2^2c_K+c_1^2c_L+2c_1c_2c_L)\}^{1/2}]. \quad (8\text{-}3)$$

We have the following result as in Table 3.

iA. The relative share for workers rises when c_1 and/or c_L rises, while it declines when c_2 and/or c_K rises.

iiA. The relative share for capitalists rises when c_2 and/or c_K rises, while it declines when c_1 and/or c_L rises.

	c_1=c_2=c_K=c_L=1	c_1=1.2	c_2=1.2	c_L=1.2	c_K=1.2
$w*Ls*/p*qs$	0.125	0.136364	0.113636	0.138097	0.112486
$\pi_0*/p*qs*$	0.5	0.5	0.5	0.5	0.5
$r*K_0/p*qs*$	0.375	0.363636	0.386364	0.361903	0.387514

Table 3. Relative income shares when c_i rises to 1.2 (i= 1, 2, L, K)

4.2 Income Distribution Inequality

First, utilizing Gini coefficient, we can show that the innovations of ICTs change the inequality in either way, depending on the parameters, c_1, c_2, c_K, and c_L. When (10-4) is assumed, for example, Gini coefficient for {$w*Ls*$, π_0*, $r*K_0$}, G_0, is computed as G_0=0.25. When c_i rises to 1.2 while others remain the same at 1, (i= 1, 2, L, K), for example, Gini coefficients for {$w*Ls*$, π_0*, $r*K_0$} , G_1, are computed as in what follows. Thus, inequality rises when c_2 and/or c_K rises, while inequality declines when c_1 and/or c_L rises.

	c_1=1.2	c_2=1.2	C_L=1.2	C_K=1.2
G_1	0.242424	0.257576	0.241268	0.258343

Table 4. G_1 when c_i rises to 1.2 (i= 1, 2, L, K)

Second, in terms of Atkinson index, we have the same result. Thus, inequality rises when c_2 and/or c_K rises, while inequality declines when c_1 and/or c_L rises.

	I_A^0	I_A^1 (c_1=1.2)	I_A^1 (c_2=1.2)	I_A^1 (c_L=1.2)	I_A^1 (c_K=1.2)
α=–10	0.581455	0.543407	0.619504	0.537602	0.623355
α=1/3	0.0911971	0.0812077	0.102548	0.0797949	0.103779
α=10/11	0.0114679	0.0103535	0.0127158	0.0101947	0.0128499

Table 5. I_A when c_i rises to 1.2 (i= 1, 2, L, K)

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

The aim of this section is to examine whether we have the tendency in Table 3 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 (10-4)

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 (10-4). We start from the computation of general equilibrium.
When (10-4) is satisfied, we can compute equilibrium prices by the Newton method:

$p^*=22.5$, $r^*=0.125$. (5-3)

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.

iB. The relative share for workers rises when c_2 and/or c_K rises, while it declines when c_1 and/or c_L rises.

iiB. The relative share for capitalists rises when c_1 and/or c_L rises, while it declines when c_2 and/or c_K rises.

	$c_1=c_2=c_K=c_L=1$	$c_1=1.2$	$c_2=1.2$	$c_L=1.2$	$c_K=1.2$
w^*Ls^*/p^*qs	0.333333	0.326656	0.340147	0.324243	0.342241
π_0^*/p^*qs^*	0.5	0.5	0.5	0.5	0.5
r^*K_0/p^*qs^*	0.166667	0.173344	0.159853	0.175757	0.157759

Table 6. Relative income shares when c_i rises to 1.2 (i= 1, 2, L, K)

5.2 Income Distribution Inequality

First, utilizing Gini coefficient, we can show that the innovations of ICTs change the inequality in either way, depending on the parameters, c_1, c_2, c_K, and c_L. When (10-4) is assumed, for example, Gini coefficient for $\{w^*Ls^*, \pi_0^*, r^*K_0\}$, G_0, is computed as $G_0=0.2222222$. When c_i rises to 1.2 while others remain the same at 1, (i= 1, 2, L, K), for example, Gini coefficients for $\{w^*Ls^*, \pi_0^*, r^*K_0\}$, G_1, are computed as in what follows. Thus, inequality rises when c_2 and/or c_K rises, while inequality declines when c_1 and/or c_L rises.

	$c_1=1.2$	$c_2=1.2$	$c_L=1.2$	$c_K=1.2$
G_1	0.217771	0.226765	0.216162	0.228161

Table 7. G_1 when c_i rises to 1.2 (i= 1, 2, L, K)

Second, in terms of Atkinson index, we have the same result. Thus, inequality rises when c_2 and/or c_K rises, while inequality declines when c_1 and/or c_L rises.

	I_A^0	I_A^1 ($c_1=1.2$)	I_A^1 ($c_2=1.2$)	I_A^1 ($c_L=1.2$)	I_A^1 ($c_K=1.2$)
$\alpha=-10$	0.4419938	0.419684	0.464783	0.411631	0.471789
$\alpha=1/3$	0.0603296	0.0567383	0.0643526	0.0555236	0.0656637
$\alpha=10/11$	0.0079771	0.00756195	0.00843989	0.00742113	0.00859022

Table 8. I_A when c_i rises to 1.2 (i= 1, 2, L, K)

6. CONCLUSIONS

This paper examined the effects of four elements in innovation on the income distribution. The 1st element is the efficiency improvement of the labor input through ICTs, and the 2nd element the one of capital input. Since the special feature of ICTs consists in the fact that quality of life improves through ICTs, the 3rd element is the improvement of the quality of consumption good through ICTs, and the 4th is the one of leisure hours. In Section 2, the production function is specified by Cobb-Douglas type where the efficiency improvement implies the *additive type* as in the traditional argument. Under this assumption, the ICT innovation cannot change the income distribution at all. When measured in terms of Gini coefficient and Atkinson index, there is no change in income inequality before and after the ICT innovation. In Section 3, the production function is specified by Cobb-Douglas type where the efficiency improvement implies the *structural type*. 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 Gini coefficient and Atkinson index, change in income inequality crucially depends on the parameters other than those of the four elements. In Section 4, the production function is 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 change in income inequality, inequality expands when the 2nd element and/or the 4th element improve, while inequality declines when the 1st and/or the 3rd element improve. In Section 5, the production function is 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, are completely opposite to those in the previous section. Meanwhile, the same conclusion holds with respect to the change in income inequality. Thus, it was shown by these simulations that theoretically, no definite relation holds between the ICT innovation and income distribution and its inequality. In order to derive the definite relation, one must examine what type of production function the economy has.

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