Centro Sraffa

Waste disposal and recycling in a Sraffian approach to environmental economics

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Background of my research

Background of my research (1)

- Analysis of the nature of reproductive aspects of capitalist economy
- Exploration into characteristics of a steady state of an economy; income distribution, gravitation of profit rates and so on
- Joint production and its application to environmental problems

Background of my research (2)

- An analysis of reproductive aspects of a capitalist economy can be applicable to sustainable development.
- Sustainability is a concept of economy and society in a long run.
- Thus, it is quite natural to apply the Sraffa model to environmental problems.

Background of my research (3)

- One more thing; pollutants and other substances which cause environmental degradation can be regarded as joint products.
- The Sraffian joint production analysis can be utilized for analysis of pollution problems and waste disposal problems.

Background of my research (4)

- To analyse environmental problems, however, it is essential to take quantity aspects into account.
- Von Neumann and Leontief types of analyses are useful for analysing quantity aspects of an economy.
- Constant returns to scale are assumed in those models, although they are not in the Sraffa model.

Background of my research (5)

- Steedman’s “Positive profits with negative surplus value” gave me an important hint for analysing environmental problems.
- Negative value appears in Steedman’s example, if there is an inferior process.
- Negative price should appear if an inferior process (with a profit factor) must be used under certain conditions.
- Materials with negative price can be considered bads or dis-commodities.

Background of my research (6)

- Assumptions of “free disposal” and “a rule of free goods” must be abandoned when we analyse environmental problems.
- An assumption of “costly disposal” must be adopted instead.
- Pollutants and other substances which give bad effects to environment are considered bads or dis-commodities.

Background of my research (7)

- Then, the notion of a long-run equilibrium must be reconsidered.

Price system

$$(1+r)pA + wl \geqq pB \text{ and}$$
$$(1+r)pAx + wlx = pBx \quad p \geqq 0 \text{ and } x \geqq 0$$

Quantity system

$$(1+g)Ax + c \leqq Bx \text{ and}$$
$$(1+g)pAx + pc = pBx$$

Free disposal and a rule of free goods.

Background of my research (8)

- Sraffa analysed an economy in which commodities are produced by means of commodities.
- Then, it is quite natural to apply his analysis to an economy in which commodities are produced by means of dis-commodities (bads, waste, end-of-life products and so on) as well as commodities.

Analyses of waste disposal and recycling

Analysis of treatment of industrial waste (1)

Normal sector

Abatement and recycling sector

$$\tilde{A} = \begin{pmatrix} \overbrace{A}^{n} & \overbrace{A_W}^{k} \\ O & I_k \end{pmatrix} \begin{matrix} \}n \\ \}k \end{matrix} \qquad \tilde{B} = \begin{pmatrix} \overbrace{I_n}^{n} & \overbrace{B_W}^{k} \\ W & O \end{pmatrix} \begin{matrix} \}n \\ \}k \end{matrix} \qquad l = (\overbrace{l_A,}^{n} \;\; \overbrace{l_W}^{k})$$

Input of residuals such as end-of-life products

Output of residuals such as end-of-life products

Analysis of treatment of industrial waste (2)

A cost-price relationship and a supply-demand relationship:

$$\begin{cases} p\tilde{B} & \leq & (1+r)p\tilde{A} + wl \\ p\tilde{B}x & = & (1+r)p\tilde{A}x + wlx \\ x_A + B_W x_W & \geq & (1+g)\left(Ax_A + A_W x_W\right) + C \\ p_A\left(x_A + B_W x_W\right) & = & (1+g)p_A\left(Ax_A + A_W x_W\right) + p_A C \\ W x_A & \leq & (1+g)x_W + q \\ p_W W x_A & = & (1+g)p_W x_W + p_W q \end{cases}$$

$p = (p_A, p_W)\,, x = \begin{pmatrix} x_A \\ x_W \end{pmatrix}$: Price and quantity vectors

$\tilde{C} = \begin{pmatrix} C \\ q \end{pmatrix}$: Consumption and quantity restriction vector

Waste disposal into natural environment is limited by q.

Analysis of treatment of industrial waste (2)

A special case: a constraint on disposal of residuals is binding.

$$\begin{cases} p_A + p_W W = (1+r) p_A A + w l_A \\ p_A B_W = (1+r)\left(p_A A_W + p_W\right) + w l_W \end{cases}$$

$$p_A = w\left(l_A + \frac{l_W W}{1+r}\right)\left[I - \left\{(1+r)\left(A + \frac{A_W W}{1+r}\right) - \frac{B_W W}{1+r}\right\}\right]^{-1}$$

On certain reasonable assumptions, p_A is positive.

$$p_W = w\left(l_A + \frac{l_W W}{1+r}\right)\left[I - \left\{(1+r)\left(A + \frac{A_W W}{1+r}\right) - \frac{B_W W}{1+r}\right\}\right]^{-1}\left[B_W - (1+r)A_W\right] - w l_W$$

On certain reasonable assumptions, p_W is negative.

Analysis of treatment of industrial waste (3)

A special case: a constraint on disposal of residuals is binding.

$$x_A = \left[I - \left\{ (1+g) \left(A + \frac{A_W W}{1+g} \right) - \frac{B_W W}{1+g} \right\} \right]^{-1} \left[\frac{w - p_W q}{p_A c(p_A)} c(p_A) + \frac{1}{1+g} \left\{ B_W - (1+g) A_W \right\} q \right]$$

$$\begin{aligned} x_W \quad = \quad & \frac{1}{1+g} W \left[I - \left\{ (1+g) \left(A + \frac{A_W W}{1+g} \right) - \frac{B_W W}{1+g} \right\} \right]^{-1} \left[\frac{w - p_W q}{p_A c(p_A)} c(p_A) \right. \\ & \left. + \frac{\left\{ B_W - (1+g) A_W \right\} q}{1+g} \right] - \frac{q}{1+g}. \end{aligned}$$

On certain conditions (i.e., q is sufficiently small), both x_A and x_W are non-negative.

Analysis of treatment of industrial waste (4)

A more general case.

$$
\begin{cases}
p\hat{B} \leq (1+r)p\hat{A} + wl \\
p\hat{B}x = (1+r)p\hat{A}x + wlx \\
\hat{B}x \geq (1+g)\hat{A}x + \left(c\left(p_A, \tilde{p}_W; q\right)^T, -q^T, 0\right)^T \\
p\hat{B}x = (1+g)p\hat{A}x + p\left(c\left(p_A, \tilde{p}_W; q\right)^T, -q^T, 0\right)^T \\
r = g \\
p \equiv (p_A, \tilde{p}_W, v_W) > 0 \quad \tilde{p}_{Wi} \cdot v_{Wi} = 0 \quad x > 0,
\end{cases}
$$

Apply Gale-Nikaido-Debreu lemma to the above system.

Analysis of treatment of industrial waste (5)

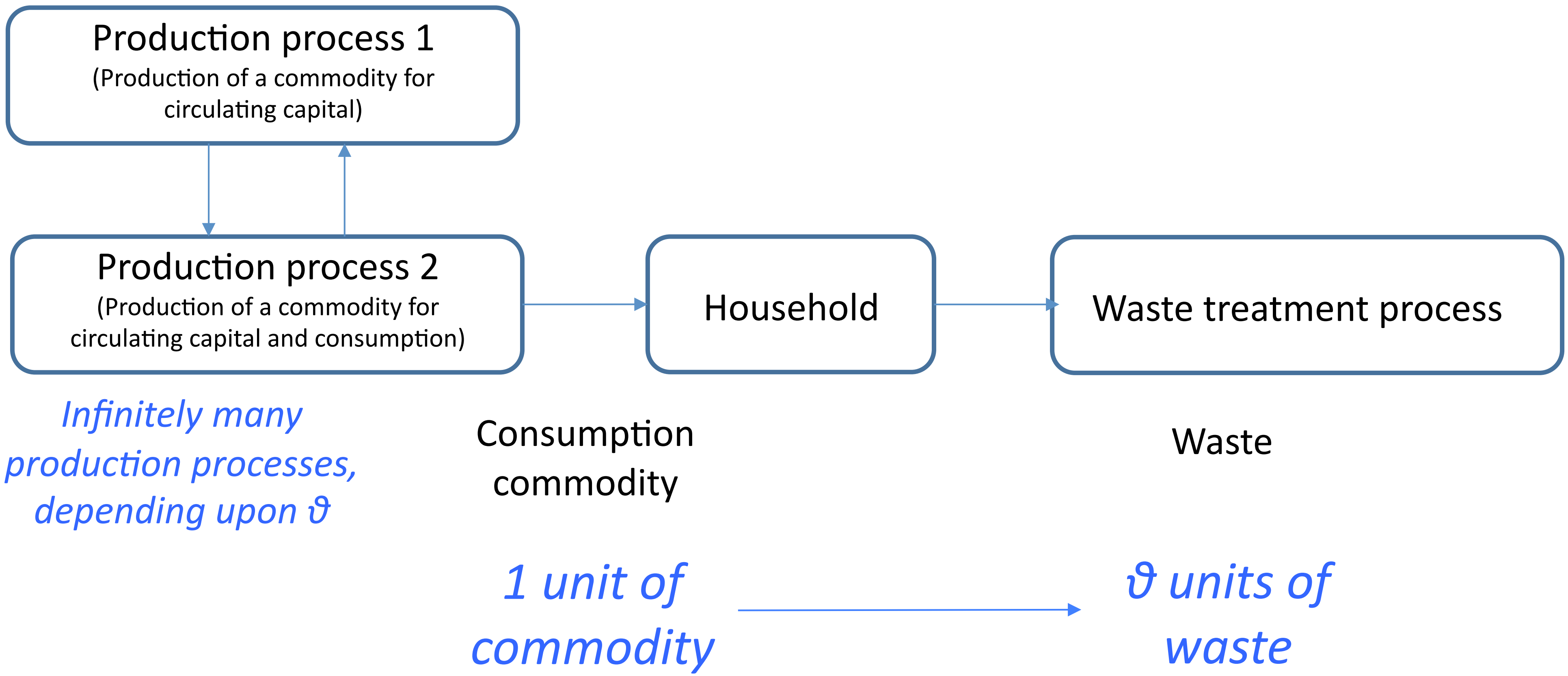
$$\hat{A} = \begin{pmatrix} A & A_W \\ \dfrac{W_A}{1+g} & \dfrac{W_W}{1+g} \\ -\dfrac{W_A}{1+g} & -\dfrac{W_W}{1+g} \end{pmatrix} \quad \hat{B} = \begin{pmatrix} I_n & B_W \\ O & (1+g)E_k \\ O & -(1+g)E_k \end{pmatrix}.$$

$$\Omega(g) \equiv \hat{B} - (1+g)\hat{A} = \begin{pmatrix} I_n - (1+g)A & B_W - (1+g)A_W \\ -W_A & (1+g)E_k - W_W \\ W_A & -(1+g)E_k + W_W \end{pmatrix}$$

Analysis of treatment of household waste (1)

- Waste is classified into two categories; industrial waste and household waste.
- The former is analysed in the framework in a Sraffian joint production system.
- The latter can also be analysed in a similar way.

Analysis of treatment of household waste (2)



Analysis of treatment of household waste (3)

Input-output structure

Input *Output*

$$A(\theta) = \begin{pmatrix} a_{11} & a_{12}(\theta) & a_{13} \\ a_{21} & a_{22}(\theta) & a_{23} \\ 0 & 0 & 1 \end{pmatrix} \to \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$L(\theta) = (l_1, \; l_2(\theta), \; l_3)$$

Production process 1 — Production process 2 — Waste treatment process — No output from the waste treatment process

$$C \equiv c \begin{pmatrix} 0 \\ 1 \\ \theta \end{pmatrix}$$: Consumption basket vector

Discharge of household waste

Analysis of treatment of household waste (4)

Basic equations

Price equation system

$$\begin{cases} (1+r)(p_1 a_{11} + p_2 a_{21}) + w l_1 = p_1 \\ (1+r)\left\{p_1 a_{12}(\theta) + p_2 a_{22}(\theta)\right\} + w l_2(\theta) = p_2 \\ (1+r)(p_1 a_{13} + p_2 a_{23} + p_3) + w l_3 = 0 \\ p_2 = 1, \end{cases} \tag{1}$$

Quantity equation system

$$\begin{cases} (1+g)\left\{a_{11} x_1 + a_{12}(\theta) x_2 + a_{13} x_3\right\} = x_1 \\ (1+g)\left\{a_{21} x_1 + p_2 a_{22}(\theta) x_2 + a_{23} x_3\right\} + c = x_2 \\ (1+g) x_3 = \theta c \\ l_1 x_1 + l_2(\theta) x_2 + l_3 x_3 = 1. \end{cases} \tag{2}$$

Analysis of treatment of household waste (5)

- Unless an upstream policy is introduced, households are supposed to pay for waste disposal to a waste treatment sector.
- The following results are not affected essentially even if a municipality is assumed to be responsible for waste treatment.
- Thus, $w = \underbrace{c}_{\text{Payment for consumption}} - \underbrace{p_3\theta c}_{\text{Payment for waste treatment}} = (1 - p_3\theta)c$ holds. (Notice $p_3 \leq 0$.)

Analysis of treatment of household waste (6)

Wage-profit curve:

$$w = \frac{\{1-(1+r)a_{11}\}\{1-(1+r)a_{22}(\theta)\}-(1+r)^2 a_{21}a_{12}(\theta)}{(1+r)l_1 a_{12}(\theta)+l_2(\theta)\{1-(1+r)a_{11}\}}$$

A *wage-profit frontier* is obtained as the envelope of the wage-profit curves when parameter θ is supposed to be chosen according to the cost-minimization principle.

Analysis of treatment of household waste (7)

Consumption-growth curve:

$$c = \frac{(1+g)\left[\{1-(1+g)a_{11}\}\{1-(1+g)a_{22}(\theta)\} - (1+g)^2 a_{21}a_{12}(\theta)\right]}{(1+g)\left[l_1 a_{12}(\theta) + l_2(\theta)\{1-(1+g)a_{11}\}\right] + \gamma(g;\theta)}$$

$$\begin{aligned}\gamma(g;\theta) \equiv \ & \theta\left[(1+g)l_1\left(a_{13}\{1-(1+g)a_{22}(\theta)\} + a_{12}a_{23}\right)\right.\\ & +(1+g)l_2(\theta)\left(\left(1+g\right)a_{13}a_{21} + a_{23}\{1-(1+g)a_{11}\}\right)\\ & \left. +l_3\left(\{1-(1+g)a_{11}\}\{1-(1+g)a_{22}(\theta)\} - (1+g)^2 a_{21}a_{12}(\theta)\right)\right]\end{aligned}$$

A *consumption-growth frontier* is obtained as the envelope of the consumption-growth curves when parameter θ is supposed to be chosen according to the maximization per capita consumption.

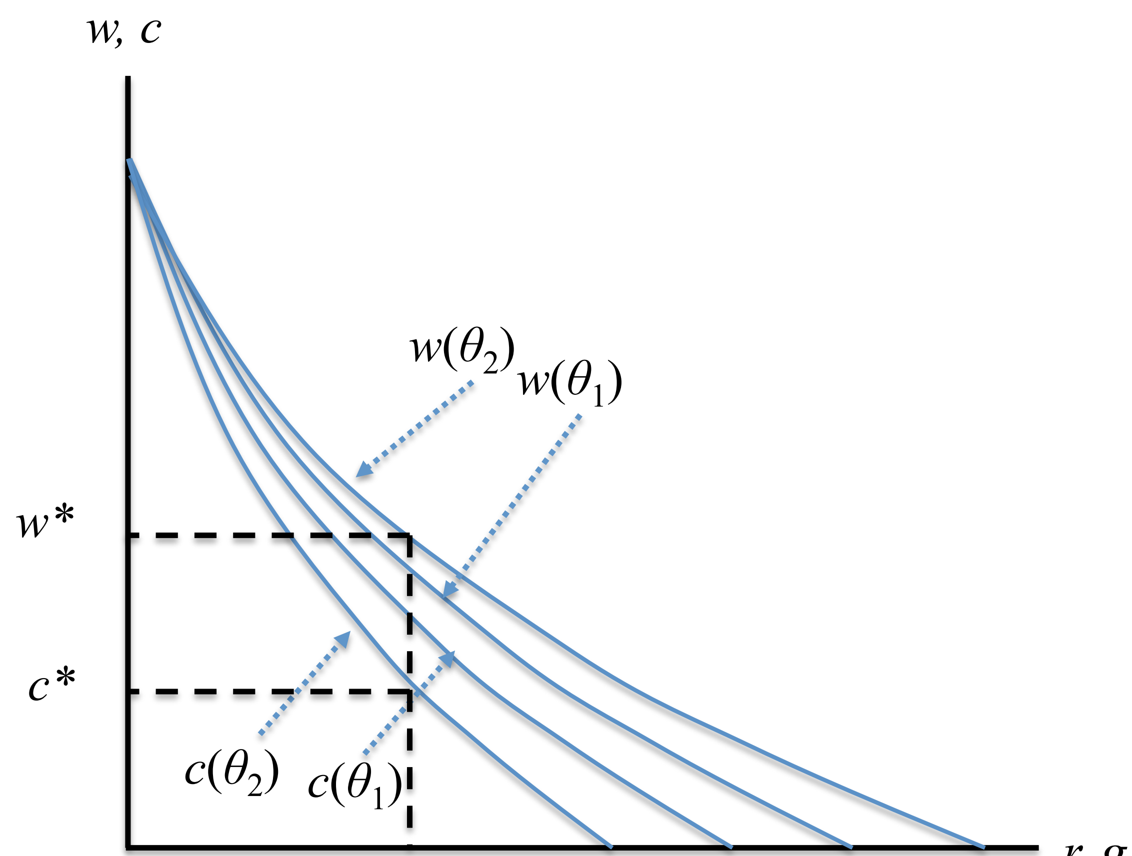
Analysis of treatment of household waste (8)

- There is a gap between wage-profit and consumption-growth frontiers.
- The technique which maximizes a wage rate does not necessarily maximizes per capita consumption even when $r = g$ holds.
- The following situation could happen;

$$c(\theta_2) < c(\theta_1) < w(\theta_1) < w(\theta_2)$$

$$\text{for } \theta_1 < \theta_2.$$

Analysis of treatment of household waste (9)



Analysis of treatment of household waste (10)

$$
\begin{cases}
(1+r)(p_1a_{11}+p_2a_{21})+wl_1=p_1 \\
(1+r)\{p_1a_{12}(\theta)+p_2a_{22}(\theta)-\delta p_3\}+wl_2(\theta)=p_2 \\
(1+r)(p_1a_{13}+p_2a_{23}+p_3)+wl_2=0 \\
p_2=1,
\end{cases}
$$

A policy variable: Producers are responsible financially for waste treatment of the relevant commodity.

$$
\begin{cases}
(1+g)\{a_{11}x_1+a_{12}(\theta)x_2+a_{13}x_3\}=x_1 \\
(1+g)\{a_{21}x_1+a_{22}(\theta)x_2+a_{23}x_3\}+c=x_2 \\
(1+g)x_3=\theta c \\
l_1x_1+l_2(\theta)x_2+l_3x_3=1
\end{cases}
$$

Analysis of treatment of household waste (11)

A wage-profit frontier

$$w = \frac{\det\left[I - (1+r)A^{\dagger}(\theta,\delta)\right]}{(1+r)l_1 a_{12}(\theta,\delta) + l_2^{\dagger}(\theta,\delta)\left\{1 - (1+r)a_{11}\right\}}$$

A consumption-growth frontier

$$c = \frac{\det\left[I - (1+g)A^{\dagger}(\theta,\delta)\right]}{(1+g)l_1 a_{12}(\theta,\delta) + l_2^{\dagger}(\theta,\delta)\left\{1 - (1+g)a_{11}\right\}}$$

There is no gap between two frontiers; the technique which maximizes the wage rate also maximizes per capita consumption.

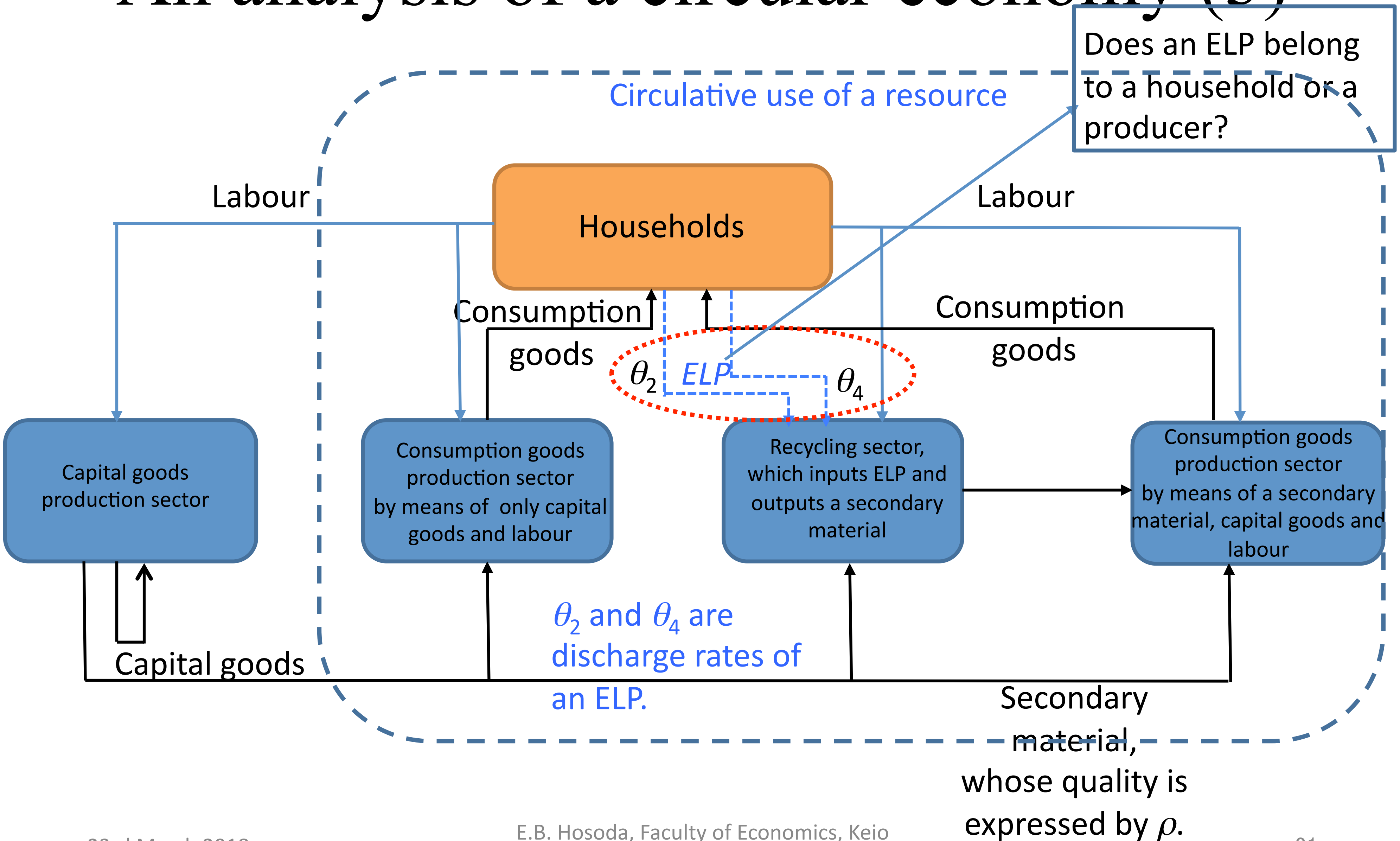
An analysis of a circular economy (1)

- "A circular economy" (CE) has become one of the most important concepts for a modern capitalist economy.
- Circulative use of resources is a crucial factor for making a circular economy.
- Rental or lease of products is considered to promote circulative use of resources and design-for-environment (DfE).
- Product service or servicizing is a similar idea.
- All those concepts imply a change of ownership of an end-of-life product from a household to a producer.

An analysis of a circular economy (2)

- Extended producer responsibility (EPR) is a variation of the idea.
- EPR means that producers are responsible financially or physically for treatment of end-of-life products which they have produced.
- Free takeback of an end-of-life product is one type of EPR, since producers are required to take back end-of-life products without charging waste disposal fee on consumers.
- Does EPR prompt design-for-environment (DfE), contributing to creation of a circular economy?

An analysis of a circular economy (3)



An analysis of a circular economy (4)

Wasted plastics

Sorted by an optical sorter

High quality secondary plastic

Car parts

Sorted by a traditional way

Low quality secondary plastic

Tetra pot and so on

An analysis of a circular economy (5)

Households' ownership economy

$$\begin{cases} (1+r)p_1 a_{11} + wl_1 &= p_1 \\ (1+r)p_1 a_{12}(\theta_2) + wl_2(\theta_2) &= p_2 \\ (1+r)\{p_1 a_{13}(\rho) + p_3 a_{33}\} + wl_3(\rho) &= p_{4\rho} \\ (1+r)\{p_1 a_{14}(\rho,\theta_4) + p_{4\rho} a_{44}\} + wl_4(\rho,\theta_4) &= p_2 \end{cases}$$

Producers' ownership economy

$$\begin{cases} (1+r)p_1 a_{11} + wl_1 &= p_1 \\ (1+r)p_1 a_{12}(\theta_2) + wl_2(\theta_2) &= p_2 + p_3\theta_2 \\ (1+r)\{p_1 a_{13}(\rho) + p_3 a_{33}\} + wl_3(\rho) &= p_{4\rho} \\ (1+r)\{p_1 a_{14}(\rho,\theta_4) + p_{4\rho} a_{44}\} + wl_4(\rho,\theta_4) &= p_2 + p_3\theta_4. \end{cases}$$

An end-of-life product belongs to a producer.

An analysis of a circular economy (6)

When ownership of an ELP belongs to producers, there is no gap between wage-profit and consumption growth frontiers.

$$w^* \geq \frac{\{1-(1+r)a_{11}\}\{A(r)+\theta_2\}}{A(r)B(r)+\theta_2 C(r)} \equiv w(\rho, \theta_2, \theta_4).$$

$$\begin{aligned} c^*(\rho, \theta_2, \theta_4) &\equiv x_2 + x_{4\rho} \\ &= \frac{\{1-(1+g)a_{11}\}\{\theta_2 + A(g)\}}{A(g)B(g)+\theta_2 C(g)} \end{aligned}$$

Variables which represent DfE.

The cost-minimizing principle of choice of technique realizes maximum wage rate in producers' ownership economy, but it is not necessarily so in households' ownership economy.

An analysis of a circular economy (7)

- There are two effects of DfE (design for environment) in a producers' ownership economy; one is the direct effect which reduces the amount of an ELP, while the other is the indirect effect which weakens the adverse effects of enhancement of the quality of a secondary material on the amount of inputs.

An analysis of a circular economy (7)

- If an ELP is bads, it is more likely that DfE effects appear in a producers' ownership economy.
- If an ELP is goods, DfE effects do not appear in a producers' ownership economy.
- There is, however, a case in which DfE effects do not appear even when an ELP is bads in a producers' ownership economy.

Conclusion (1)

- The Sraffian analysis of commodities produced by means of commodities is well suited to analyses of commodities produced by means of dis-commodities (waste, residuals, end-of-products and so on).
- Circulative use of resources can be a good theme for Sraffians, although some modifications may be required.

Conclusion (2)

- Extended producer responsibility, design-for-environment and so on which are crucial factors for a circular economy can be easily accommodated in the analysis.
- Some useful policy implications for a circular economy can be deduced from Sraffian analyses.