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Sustainable Development Goals as a problem in the change of techniques

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I. Cambridge controversies: classical/post-Keynesian versus neo-classical paradigms

The SDG aim at a systematic transformation of the world's economic production structure from the present one that is harmful to environment and that is increasingly failing on economic and social cohesion.

This requires a technological change that will have massive distributional impacts. The question should therefore be viewed as a problem in the choice of techniques. For the mainstream, technology is determined by demand and relative prices. For post-Keynesians technology determines relative prices.

In this respect in the 1960s a debate developed between the "two Cambridges" (US and UK), later called “the capital controversies”. The main issue at stake was the re-switching of techniques, which can arise in the choice of techniques. There is a (re-)switch, when one technology is the most profitable at a certain profit rate, and is then discarded at a lower profit rate, to then become again the best technique at an even lower profit rate. In this case, there is no inverse relationship between the “quantity of capital” and its “price”.

The US side finally acknowledged that re-switching was a theoretical possibility (Samuelson, 1966), but hinted that it was essentially irrelevant for practical purposes. Further on the question was essentially forgotten (see Pasinetti, 2000). Bharadwaj ([1970], 1989) later showed that there are as many “switch points” as basic commodities, while Pasinetti (1986) stressed the differences between the static world of the “exchange paradigm”, under which no dynamic substitution can take place, and the “production paradigm” in which time forms an essential element.

II. Leontief's Static/stationary equilibrium (single period)

Leontief's input-output model can be read with classical and neo-classical glasses. It focuses on a single period but can also be the starting point for continuation analysis. Assuming n commodities including labour, the "closed" and "open" Leontief systems can be written, respectively for quantities and for prices, as:

Closed model:
$$\begin{cases}(I-A)q=0\\ p^t(I-A)=0\end{cases} \qquad (1a)$$

Open model:
$$\begin{cases}(I-A)q=y\\ a_n q=LF\end{cases} \qquad (1b)$$

A is a nxn square technology matrix with elements $a_{ij,}$ i, j=1,...n-1, giving the amount of commodity i necessary to produce a unit of commodity j. In the closed model the last row of A is made of the labour coefficients, while the last column provides the final demand coefficients. The column vector of output produced is q and the row vector of prices is p.

II. 1 Neo-Classical (Steenge, 2004)

One can add a satellite environmental block in an open Leontief quantity model in the following way:

$$\begin{bmatrix} I-A_{11} & -A_{12} \\ A_{21} & -I+A_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \end{bmatrix}$$

where: A_{11} is the Leontief matrix, A_{21} is a of emission coefficients, A_{12} is the matrix of input coefficients of the abatement industries, A_{22} is the matrix of output of pollutants per unit of eliminated pollutant, x_1 is the vector of total outputs of traditional goods, x_2 is the vector of total of pollutants being abated, c_1 if the vector of final consumption of the traditional goods, c_2 is the vector of tolerated levels of pollutants.

II. Leontief's Static/stationary equilibrium (single period)

II. 2 Sraffian (Pasinetti, 1977)

The price variant of the Leontief closed model shows that prices depend on technology:

$$p = a_n[I - (1 + \bar{\pi})A]^{-1}w \qquad (2)$$

With wages paid in the beginning of the period as in the classical tradition (Graziani, 1994), the solution of the model gives a wage-profit possibility frontier that is slightly changed:

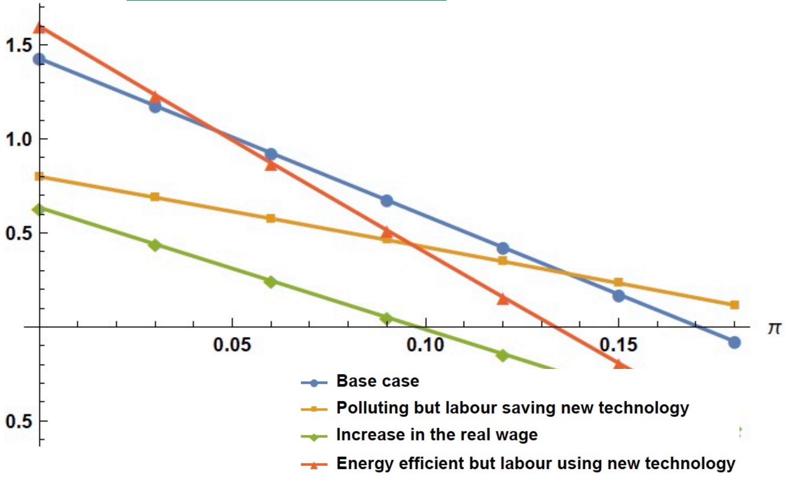
$$p[I - (1 + \pi)A] = a_n w \xrightarrow{becomes} p[I - (1 + \pi)A] = a_n w(1 + \pi)$$

, taking the composite commodity as numéraire and including subsistence wage in A, one gets an "environmental cost"/profit possibility frontier :

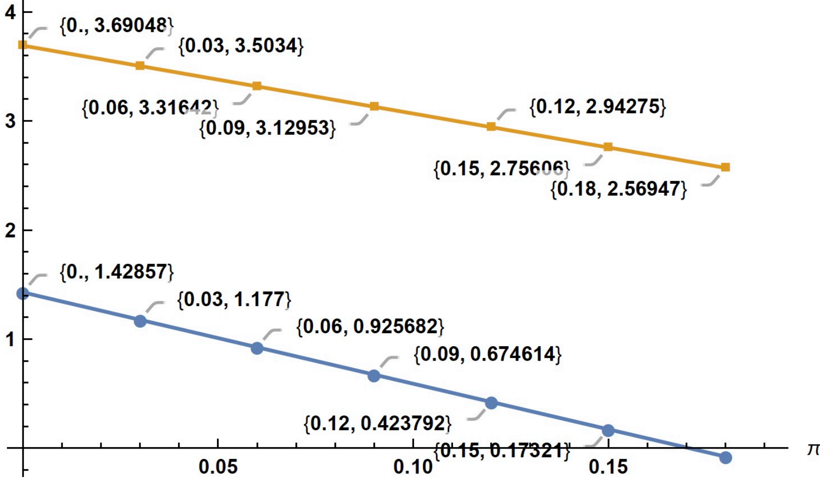
$$\rho = \frac{1}{\alpha_{CO^2}[I - (1 + \pi)(A + c\alpha_n)]^{-1}c}$$

, which can then be used to illustrate some scenarios :

Static: Given A



Towards dynamics: Changing A



III. Pasinetti Structural Dynamics (continuation analysis)

III. 1 Vertical Integration: open Leontief system with depreciation (Pasinetti, 1973/80)

The Leontief open system with depreciation and investment for quantities is:

$$\begin{cases} (I - A^{\ominus})x_t = y_t & (3a) \\ l_t x_t = L_t & (3b) \\ s_t = A x_t & (3c) \end{cases}$$

where: x_t = vector of the physical quantities (n-1 consumption goods and n-1 capital goods), y_t = vector of the physical net product of the economic system; s_t = vector of the stock physical capital required at the start of each period; $A^{\ominus} = A^c + A^f \hat{\delta}$ whose elements represent that part of the beginning of year stock of capital goods that are used up each year in the production process; it is obtained from $A^f \hat{\delta}$ = matrix of capital consumption flows, and $A^c = X^c \hat{x}$, which is the matrix of circulating capital coefficients and $A^f = X^f \hat{x}$, which is the matrix of fixed capital coefficients. These are obtained from X^c = Matrix of circulating capital flows, X^f = Matrix of fixed capital stocks and $\hat{\delta}$ = diagonal matrix of fixed capital consumption coefficients. Finally $A = A^{\ominus} + (1 - \hat{\delta})A^f$. For prices the system is the same as for the closed system, with price vector $p_t = [p_1(t) \quad \cdots \quad p_m(t)]$.

The vertical integration coefficients are derived by solving the system (3). They are given by L_t, v_t and H:

$$\begin{cases} x_t = (I - A^{\ominus})^{-1} y_t = L y_t & (4a) \\ L_t = l_t (I - A^{\ominus})^{-1} y_t = v_t y_t & (4\,b) \\ s_t = A(I - A^{\ominus})^{-1} y_t = H y_t & (4c) \end{cases}$$

III. Pasinetti Structural Dynamics (continuation analysis)

III. 2 Vertical Integration: quantities (Pasinetti, 1973/80)

The columns in matrix H are vectors of vertically integrated production capacity. If they are taken as unit of measure for the capital goods, the static, single period system can finally be written in its vertically integrated form, which for quantities is given by (5) and its solution, when different from zero (see below), is given by (6). The n-1 consumption goods are: $x_1, \cdots x_{n-1}$ and the n-1 capital goods are: $x_{k_1}, \cdots x_{k_{n-1}}$.

$$\begin{bmatrix} -1 & & & & & & & c_{1n} \\ & -1 & & & & & & c_{2n} \\ & & -1 & & & & & \vdots \\ & & & -1 & & & & c_{n-1,n} \\ \frac{1}{T_1} & & \cdots & & -1 & & \cdots & c_{k_1 n} \\ & \ddots & & & & -1 & \cdots & \vdots \\ & & \frac{1}{T_{n-1}} & & & & -1 & c_{k_{n-1} n} \\ a_{n1} & & a_{n,n-1} & a_{nk_1} & \cdots & \cdots & a_{nk_{n-1}} & -1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_{n-1} \\ x_{k_1} \\ \vdots \\ x_{k_{n-1}} \\ LF \end{bmatrix} = \begin{bmatrix} 0 \\ \vdots \\ 0 \\ \vdots \\ 0 \end{bmatrix} \quad (5)$$

$$\begin{cases} x_1 = c_{1n} LF \\ x_2 = c_{2n} LF \\ \vdots \\ x_{n-1} = c_{n-1n} LF \\ x_{k_1} = \left[c_{k_1 n} + \dfrac{c_{1n}}{T_1} \right] LF \\ x_{k_2} = \left[c_{k_2 n} + \dfrac{c_{2n}}{T_1} \right] LF \\ \vdots \\ x_{k_{n-1}} = \left[c_{k_{n-1},n} + \dfrac{c_{n-1n}}{T_1} \right] LF \end{cases} \quad (6)$$

III. Pasinetti Structural Dynamics (continuation analysis)

III. 3 Vertical Integration: prices (Pasinetti, 1973/80)

For prices, starting from the equivalent of (4), the equivalent of (5) is (7) below, where the same vertical integrated coefficients appear in the Leontief matrix, which is slightly transformed. The solution of (7) is given by (8):

$$
\begin{bmatrix}
-1 & & & \frac{1}{T_1}+\pi_1 & & & & a_{n1} \\
& -1 & & & \frac{1}{T_2}+\pi_2 & & & a_{n2} \\
& & -1 & & & \ddots & & \vdots \\
& & & -1 & & & \frac{1}{T_{n-1}}+\pi_{n-1} & a_{n,n-1} \\
\frac{1}{T_1} & & \cdots & & -1 & & \cdots & a_{nk_1} \\
& \ddots & & & & -1 & \cdots & \vdots \\
& & \frac{1}{T_{n-1}} & & & & -1 & a_{nk_{n-1}} \\
c_{1n} & \cdots & c_{n-1,n} & c_{k_1 n} & \cdots & \cdots & c_{k_{n-1},n} & -1
\end{bmatrix}
\begin{bmatrix} p_1 \\ p_2 \\ \vdots \\ p_{n-1} \\ p_{k_1} \\ \vdots \\ p_{k_{n-1}} \\ w \end{bmatrix}
=
\begin{bmatrix} 0 \\ \vdots \\ 0 \\ \vdots \\ 0 \end{bmatrix}
\quad (7)
$$

$$
\begin{cases}
p_1 = \left[a_{n1}w + a_{nk_1}\left(\frac{1}{T_1}+\pi_1\right)\right]w \\
\vdots \\
p_{n-1} = \left[a_{n,n-1} + a_{nk_{n-1}}\left(\frac{1}{T_{n-1}}+\pi_{n-1}\right)\right]w \\
p_{k_1} = a_{nk_1}w \\
\vdots \\
p_{kn-_1} = a_{nk_{n-1}}w
\end{cases}
\quad (8)
$$

The determinant of the matrixes appearing in (5) and (7) is the same and therefore the condition for their solution, which is also a full employment condition, is also the same. It is given by (9):

$$
\sum_{i=1}^{n-1} a_{ni}c_{in} + \sum_{i=1}^{n-1} a_{nk_i}c_{k_i} + \sum_{i=1}^{n-1} \frac{1}{T_i} a_{nk_i}c_{in} = 1 \quad (9)
$$

III. Pasinetti Structural Dynamics (continuation analysis)

III. 4 Structural dynamics: the model (Pasinetti, 1981)

Once the input-output original (inter-industry) model (1) and (2) is transformed in its vertical integrated (inter-sectoral) form (5) and (7), where the only inputs are capital and labour, the simple logical and pragmatic assumption to move from the single period to continuation analysis, which therefore appears acceptable, is to assume that the vertical integrated coefficients grow linearly because of exogenous technical progress, demographics and consumption patterns (given by Engel laws). The dynamics of the model are then given by:

Population	$x_n(t) = x_n(0)e^{gt}$		(10)
Productivity	$a_{nk_j} = a_{nk_0}e^{-\rho_j t}$	$j = 1,2\ldots.n-1$	(11)
Per capita demand	$a_{in}(t) = a_{in}(t-\theta)e^{r_i\theta}$	$i = 1,2,\ldots n-1$	(12)
Capital accumulation	$a_{k_in}(t) = (g+r_i)a_{in}(t)$	$i = 1,2,\ldots n-1$	(13)
Quantities	$\begin{cases} x_i(t) = Ae^{(g+r_i)\theta} \\ x_{k_i}(t) = \left(g+r_i+\frac{1}{T_i}\right)Ae^{(g+r_i)\theta} \end{cases}$	$i = 1,\ldots[n(t)-1]$	(14)
Prices	$\begin{cases} p_i(t) = Be^{-\rho_i\theta} + \left(\pi+\frac{1}{T}\right)Ce^{-\rho_{k_i}\theta} \\ p_{k_i}(t) = Ce^{-\rho_{k_i}\theta} \end{cases}$	$i = 1,\ldots[n(t)-1]$	(15)
where:	$A = a_{in}(t-\theta)x_n(t-\theta)$	$B = a_{ni}(t-\theta)\overline{w}$	(16)
Employment:	$\begin{cases} E_i(t) = Me^{(g+r_i-\rho_i)\theta} \\ E_{ki}(t) = \left(g+r_i+\frac{1}{T}\right)Ne^{(g+r_i-\rho_i)\theta} \end{cases}$	$i = 1,\ldots.n(t)-1$	(17)
where:	$M = a_{ni}(t-\theta)a_{in}(t-\theta)v^{-1}x_n(t-\theta)$	$N = a_{nk_i}(t-\theta)a_{in}(t-\theta)v^{-1}x_n(t-\theta)$	(18)
Natural Profit Rate	$\pi_i^* = g + r_i$	$i = 1,\ldots n-1$	(19)
Uniform profit rate	$\pi_e = \frac{1}{s_c}(g+r^*)$		(20)
Natural interest rate	$i^* = \sigma_w$	σ_w = *rate of wage increase*	(21)

III. Pasinetti Structural Dynamics (continuation analysis)

III. 5 Structural dynamics: the full employment condition (Pasinetti, 1981)

The dynamic equivalent of the full employment condition can be written:

$$1 = \frac{1}{\mu\nu} \sum a_{ni}(t-\theta) a_{in}(t-\theta)\, e^{(r_i - \rho_i)\theta} + \frac{1}{\mu\nu} \sum \left(g + r_i + \frac{1}{T_i} \right) a_{nk_i}(t-\theta) a_{in}(t-\theta) e^{(r_i - \rho_i)\theta} \quad (22)$$

where μ is the activity rate of the labour force and ν is the number of hours worked per year. In the words of Pasinetti:

"The conclusion is straightforward. Even if we start from an equilibrium position (i.e. even if full employment of the labour force and full productive capacity utilisation are realised at a given point of time) the structural dynamics of the economic system cause that position to change and therefore make it impossible in general to automatically maintain full employment through time." Pasinetti (1981, p. 87)

IV Choice versus change of techniques: IV 1) choice of technique

The **choice of technique** is a microeconomic cost minimisation that refers to each single production unit at a given point in time.

$$Min \begin{cases} p^{\alpha}_{k_j} K^{\alpha}_j + x^{\alpha}_{nj} w, \\ \vdots \\ \vdots \\ p^{\omega}_{k_j} K^{\omega}_j + x^{\omega}_{nj} w \end{cases} \qquad j = 1, \ldots n-1 \qquad (23)$$

Where:

$f^{\alpha}_j, f^{\beta}_j, \cdots f^{\omega}_j$	Ω *available techniques to produce* $\bar{x}_j = f^k_j(K^k_j, a^k_{nj})$
$\alpha, \beta, \cdots \omega$	*index of alternative methods*
$K^k_j \quad k = \alpha, \beta, \cdots \omega$	*vector of machines and intermediate commodities in VIS*
x^k_{nj}	*physical quantity of labour required in VIS to produce* $\bar{x}_j$
$\pi_j \quad j = 1, \cdots n-1$	*natural profit rates*
w	*wage rate*

In the a more general case, the price corresponding to (15) will be given by:

$$p_{k_i} = \left[\left(\frac{T_{k_i}}{T_{k_j} - \gamma_j - \pi_{k_i}\gamma_j T_{k_j}}\right) a_{nk_j}\right] w \quad j = 1, \ldots. n-1 \quad (24),$$

which shows that any change in the wage rate will change in the same manner the cost of all available technical methods in the same proportions, hence the choice of technique depends on the technical parameters and is independent of the wage rate. On the contrary profits appear inside the square brackets and therefore have a differential impact on the choice of technique. Pasinetti shows by derivation of (24) with respect to profit, that a technique that is profitable at a high rate of profit, may cease to be so if the rate of profit is decreased, but may become profitable again at an even lower rate (comment: different from mainstream but cost minimisation if natural profit rates).

IV Choice versus change of techniques: IV 2) change of technique

Change of technique: Over time, the choice of technique in a sequence of single periods brings to the change of techniques , which is a macro-dynamic process involving changes in all the macro and micro variables of the system (interest rate and wages, but also sectoral outputs and prices). The dynamic aspect of the change of techniques, which acts upon vertically integrated technical coefficients, is also the reason why Pasinetti rejects the neo-classical production function. While the "fixed-coefficient" production function $\overline{x_j} = f_j^k\left(K_j^k, a_{nj}^k\right)$, accepted by post-Keynesians, describes "ex post" the reality of the complementarity between factors and therefore the non-substitutability of labour and capital in the single period once new capacity is installed, the infinite substitutability of capital and labour implicit in the neo-classical production function concerns the "ex ante" choice of techniques, which cannot be envisaged within the same single period, except in special cases.

> *"This means introducing precisely those particular assumptions - i.e. stationary technical knowledge - that make the techniques which are relevant for the problem of choice coincide with the techniques which are relevant for a process of change. As has been pointed out already, this means frustrating any possibility of a dynamic analysis. Note moreover that - in spite of the superficially more elegant formulation - to assume coincidence of phenomena that are in general not coincidental is precisely the opposite of what is meant by 'generalisation'." (Pasinetti, 1981, p. 203)*

This also implies the rejection of marginal productivity, which comes out to be essentially an irrelevant concept as nothing can be changed within the single period (p. 205), after which everything changes.

V. Cost-benefit considerations: V 1) What accounting prices?

If a project will realise a change in the quantities consumed by Δq, the general idea of cost-benefit analysis is that the social impact of the project could be evaluated by $p_S \Delta q$, where p_S is the "accounting price" (or another relevant index of social utility). On the contrary, the market will evaluate the same project at $p_M \Delta q$, where p_M is the observed market price. The general idea, originating in Pigou (1932), is that to the extent that $p_S > p_M$ there is *prima facie* evidence for providing public support to the project, in principle up to an amount $p_S - p_M$.

Which prices should be used as accounting prices? It seems intuitive and reasonable to use “normative” or “equilibrium” prices. In this case the following concepts are candidates (the profit distribution assumptions are noted):

1) Market prices, if these are assumed to coincide at every moment with equilibrium prices (maximum efficiency).
2) Neo-classical equilibrium prices when the latter are not necessarily supposed to coincide with market prices.
3) "Smithian" natural prices, in the sense of prices based on labour costs and the equalisation of sectoral rates of return. A "natural remuneration" of capital would be part of natural prices.
4) Marx's production prices, based on the equalisation of sectoral profit rates to a level comprised between 0 and the maximum profit rate, which, to simplify, is the rate coming out of relation (2) when the wage is minimal at zero.
5) Long-term prices in the tradition of Garegnani, which to a large extent are a variant of Marx's reproduction prices.
6) Pasinetti's natural prices, discussed above, where profits finance investments and not more.

The most reasonable choice seem Pasinetti's natural prices because of their properties and because : 1) is unrealistic and rather useless, this covers also 2). 3) problems with labour theory of value, better use Sraffa/Pasinetti; 4) Difficult to implement with arbitrary exogenous profit rates. 5) Long-period prices: not easy to calculate either.

V. Cost-benefit considerations: V 2) Problems with normative prices

1. The second-best approach has shown that **if there is more than one departure from optimal conditions**, it is not sure that removing this "distortion" would improve general welfare (Lipsey & Lancaster, 1956-57). If one uses normal price values in a non-optimal world (or natural prices in an institutionalised context) it is then not sure what will happen.

2. In the rigorous neoclassical framework of Allais ([1981] 1989 and) the author shows that close to a situation of maximum efficiency it is possible to use neo-classical equilibrium prices to calculate the impact of a change in quantities brought by a project ($p_M \Delta q$). But **far from the maximum efficiency equilibrium, the calculation of the "loss" cannot be based on neoclassical equilibrium prices**. But what is the meaning of being close to maximum efficiency in a dynamic context characterized by technical change? In particular, what is this meaning of traditional CBA in the context of the systemic change as the one supposed to be brought by the SDG?

3. Moreover, **distribution cannot be taken as given**, as shown by the classical/post-Keynesian approach, and this is particularly clear in the natural economy of Pasinetti. It is also true for Allais' production-possibility frontier (Cingolani, 2010).

In conclusion: there is not a single objective "scientific" or technical way to calculate accounting prices, hence for SDG purposes it is better to leave them to the political choice and the negotiation between the interested stakeholders (see also discussion in Cingolani, 2021).

Conclusions

I. The inter-industry environmental impact of an investment in SDG can be calculated with a standard I-O model (neo-classically interpreted). The Sraffian interpretation shows the link between technology and relative prices. If technology changes, the arbitrage between environment and other costs ceases to be a zero sum game.

II. If one moves from inter-industry to intersectoral analysis through vertical integration, it is easy to see why the natural dynamics of a capitalist market economy is likely to evolve towards increased unemployment due to the combined effect of different sectoral rates of technical progress. Aggregate demand must be managed, potentially by the creation ex novo of new markets by the public sector to absorb the manpower released from other sectors.

III. The change in techniques takes places dynamically by the interaction between technical progress and the production technology installed, described by a fixed coefficient production function. The causality doesn't go from salaries as the prime element of costs to labour savings technical progress nor from savings to investment. A "just transition" that increases living standards and attains the environmental and social objectives is perfectly possible, but it must be well programmed, taking into account the relevant causality chains in order to avoid accumulating imbalances.

IV. Beyond the central question of what is the price structure that would incentivise the private sector to realise the SDG (which cannot be the prevailing one), there is the equally important one of the accounting prices that should be used by the public sector, in particular for setting the incentives for the private sector. It is argued that these prices are not known. It is thus proposed to agree politically on them, as there seem to be consensus that whatever they should be, they should be defined based on the existing policy objectives (Cingolani, 2021). One should also pragmatically recognize that the relevant national, regional, and local jurisdictions should be involved in their definition.

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