

RESOURCE INTRA-ACTIONS AND INTER-ACTIONS: IMPLICATIONS FOR TECHNOLOGICAL CHANGE AND ECONOMIC GROWTH

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Abstract: *W. Arthur Lewis's distinction between factors and forces of production, and Paul Romer's insightful identification of the poverty of objects and the lack of ideas, as central to economic growth rate differences across economies, have enriched economic growth theory. However, both object-idea gaps, and factor-force specialization do not make explicit intra-actions among objects and ideas on the one hand, and the inter-actions among objects and ideas on the other hand. This analysis shows that resource intra-actions and inter-actions are important to technological change, and hence to economic growth. Economies with strong positive resource intra- and inter-actions produce more output than others. In fact, intra- and inter-active economies are characterized by economies of scale (increasing returns in the broad sense) and would produce twice as much output as others, and their rates of growth are high because of it. How useful this analysis can be to policy is left to empirical investigations.*

Keywords: *resource intra-actions, resource inter-actions, intra-active and inter-active technological change, Lewis-Romer economic growth model*

JEL Code: *O41, D24, O47, O33, C65, Q00*

I. Introduction

GROWTH AND CHANGE ECONOMISTS, irrespective of their philosophical and methodological orientations, generally agree on the fundamental rule of production: output (y) is a function of productive resources commonly known as inputs or factors of production (X). While disagreements about the specific form of a production function and the importance of individual resources abound, there is little dispute among growth and change economists about the list of productive resources: labor (L), human capital (H), capital (K), land (R), and entrepreneurship (E). Given the list, classical economists have argued that output depends mainly on labor, at least in the short run. An important reason for their argument was that land came in limited supply, while capital was scarce, rudimentary, and perhaps even less productive than labor and land, and its rate of accumulation could reasonably be assumed constant. Adam Smith's (1976, Book II) discussion of the fixed and variable components of capital is interesting. However, in the outline of "law of accumulation" and the "law of population" as drivers of economic growth, capital

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accumulation led to wage improvement with a lag of 15-25 years (Angresano, 1992). But even then the wage increase was a temporary one and soon reversed by the growth of population. This suggests that capital was not considered particularly important to Smith's economy. Thus, it is not hard to understand how good economic thinking led Smith to the division of labor theory that excluded other factors of production, or how Malthus saw disaster in population growth (cf. Thompson, 1992, Chapter III).

Ricardo accepted that the supply of land was limited, but land itself comes in varying grades of quality such that the supply of land, narrowly defined, is not perfectly inelastic with respect to its own price (rent). This innovation around the Malthusian population growth scare demonstrated that scarcity is relative; it also formalized the classical overemphasis on the value of labor in production. Thus, Karl Marx (1906) noticed that capital and capital accumulation are both dynamic, yet he too was in the end trapped in Ricardo's "labor theory of value" so that $y = f(\text{Resources}) = f(X) = f(L|\bar{R}, \hat{K})$, where the vertical line means "on condition that" land is fixed (overbar) and capital, whatever amount, is given (hat).

For a while labor and capital were considered *the* factors of production until, taking their cue from Adam Smith, Frank Knight (1921) and Joseph Schumpeter (1954, 2005) extended analysis to include the role of entrepreneurship (E) in y and y -growth (cf. Benjamin Higgins, 1968, Part 2). From this general literature one can infer that economists have tended to divide resources (X) into factors (X_1) and forces (X_2) without saying so explicitly (Amavilah, 1998, Amavilah and Newcomb, 2004). For example, in a neoclassical fashion Solow (1956, 1957) and Swan (1956, 2002) represent forces as (exogenous) technical change and factors as the conventional means of production (using Marx's language) Sir W. Arthur Lewis (1965), a true new classical, retains the conventional list of the factors of production and adds to it production forces: (a) "the will to economize", (b) economic institutions, (c) government, and (d) public policy. Briefly: $y = f(\text{Resources}) = f(\text{Factors, Forces}) = f(X_1, X_2) - a \text{ fundamental innovation!}$ However, the innovation went unsung mainly because many economists know Lewis only through his "development with unlimited supply of labor" (Lewis, 1954).² A clear and emphatic statement of the distinction between factors (X_1) and forces (X_2) of production emerged for the first time from Paul Romer's (1993) insightful *object-idea gaps*. See excellent overviews of new growth theories by Mark Rogers (2003) and Nazrul Islam (2004).³

The objective of this paper is to restate the Lewis-Romer model in a simple and practical way by making as explicit as possible resource intra- actions and inter-actions. The restatement shows that resource intra-actions and inter-actions are critical to technological change and through it they explain level and growth rate differences across economies. Section II next below outlines resource

²Lewis's book was first published in 1953 and his famous article is based on that work.

³Volume 8, No. 1 of the *Journal of Economic Perspectives* (1994) carries a number of perspectives on economic growth by some of the outstanding growth and change economists including Paul Romer himself.

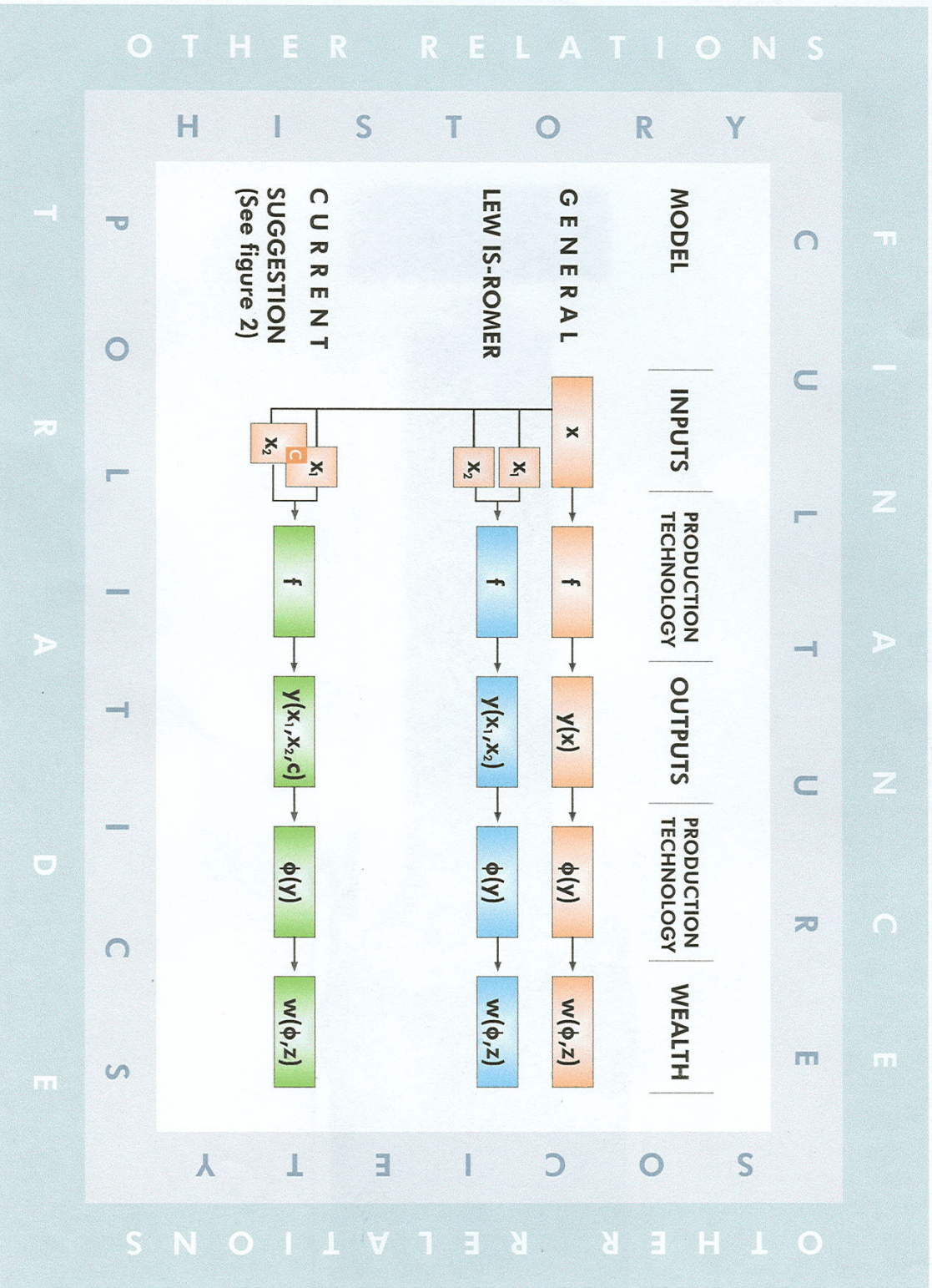


FIGURE 1 - BASIC PRODUCTION FUNCTION APPROACHES

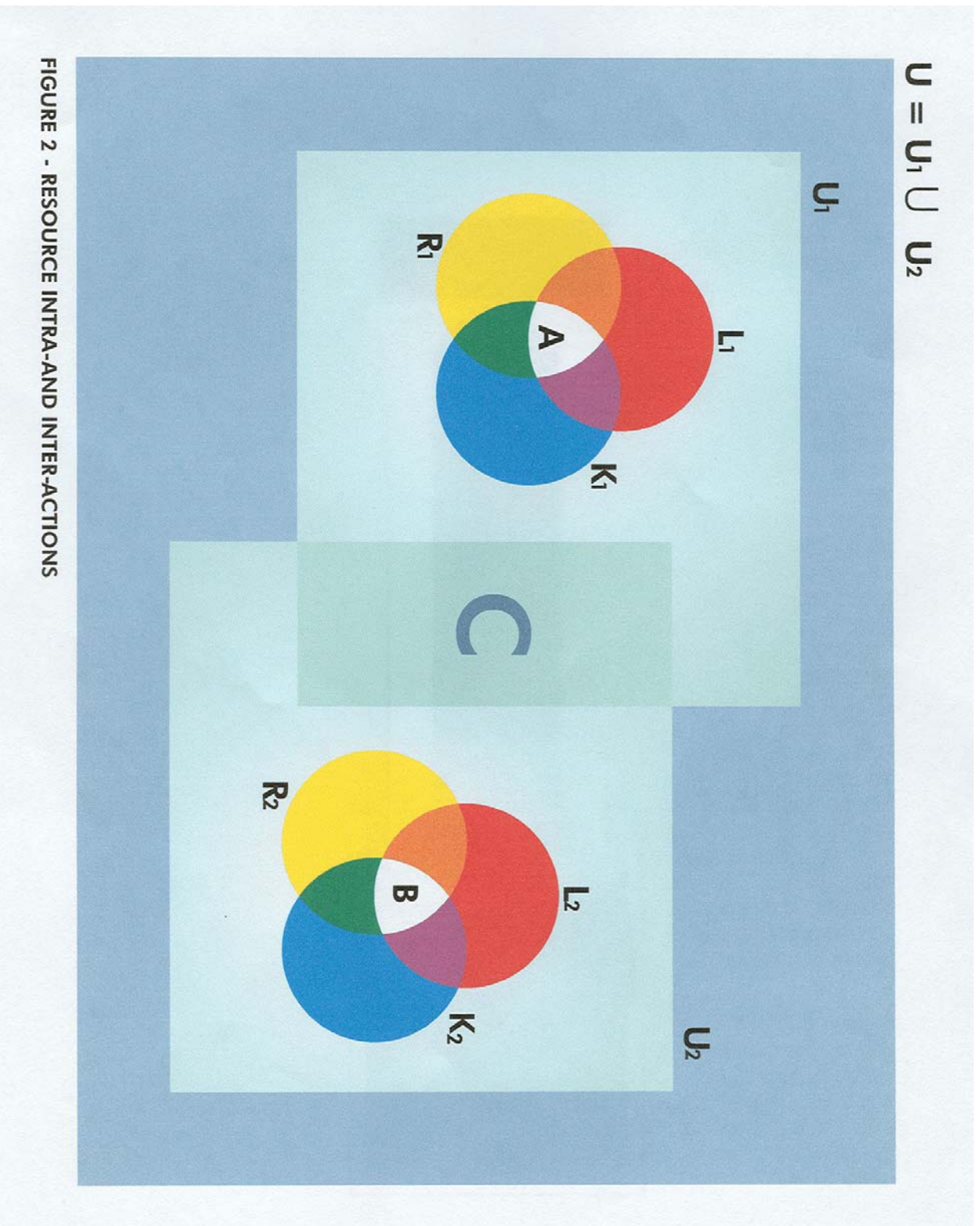


FIGURE 2 - RESOURCE INTRA-AND INTER-ACTIONS

intra-actions and inter-actions. The third section indicates that the intra- actions and inter-actions determine technological change. Section IV places technological change at the center of economic growth and is follow by Section V which summarizes the paper and describes key variables that would allow empirical tests of the model.

II. Resource intra-actions and inter-actions

Assuming an ideal economic universe (U) Figure 1 describes how the black-box f transforms resources into y , and how post-production functions Φ (packaging, marketing, storage, etc.) add value to y , thereby affecting wealth (and welfare) which in turn influence the quality and quantity of resources. Positive changes in the quantity and quality of resources shifts the production possibility frontier outward thereby enlarge production possibilities, i.e., economic growth. How fast growth is, and whether or not it is sustainable, must recognize that the production process is a social process insofar as it is surrounded by all kinds of internal environments, some of which are economic, such as the economic system, others of which are political, such as democratic institutions, and still other of which are cultural, religious, what have you (Marx, 1973, Max, 1958, 1947, Polanyi, 1957, Herskovits, 1952). Moreover, under resource globalization (localization) these internal environments are themselves affected by other external environments via international trade, finance, and other relations.

Now, assume that the economic universe (U) in Figure 1 consists of two sub-universes U_1 and U_2 , i.e., $U = U_1 \cup U_2$. U_1 produces output y_1 using Romer's objects or Lewis's specialized factors (X_1). U_2 produces y_2 utilizing Romer's ideas or Lewis's forces (X_2). Also suppose there are interdependencies (1) among objects and ideas within each sub-universe, and (2) between objects and ideas across the two sub-universes of one universe. Call the former *resource intra-actions*, and the latter *resource inter-actions*. From Figure 2 it should be clear that if $U = U_1 \Rightarrow U_2 = 0, C = 0$, then $y_1 = f(L_1^*, K_1^*, R_1^*; A)$, where $X^* = X - A$, and $A = L_1 \cap K_1 \cap R_1 \equiv \tau_1$ are object intra-actions representing object-embodied technological change. Similarly, for $X^* = X - B$, $y_2 = f(L_2^*, K_2^*, R_2^*; B)$, $B = L_2 \cap K_2 \cap R_2 \equiv \tau_2$ is technological change associated with idea intra-actions. Then the resource tie-bar between the two sub-universes are object-idea inter-actions, $C = U_1 \cap U_2 \equiv \tau_3$, signifying cross-universe technological change such that

$$y = (y_1 \cdot y_2) e^{C \equiv \tau_3} \quad (1)$$

$$= [f(L_1^*, K_1^*, R_1^*, A \equiv \tau_1) g(L_2^*, K_2^*, R_2^*, A \equiv \tau_2)] e^{\tau_3}$$

Now, giving (1) a Cobb-Douglass form produces

$$\begin{aligned}
y &= [(e^{\tau_1} L_1^{\alpha_1} K_1^{\beta_1} R_1^{\gamma_1}) (e^{\tau_2} L_2^{\alpha_2} K_2^{\beta_2} R_2^{\gamma_2})] e^{\tau_3} \\
&= [L_1^{\alpha_1} K_1^{\beta_1} R_1^{\gamma_1} (L_2^{\alpha_2} K_2^{\beta_2} R_2^{\gamma_2})] e^{\tau_1 + \tau_2 + \tau_3},
\end{aligned} \tag{2}$$

where L_i , K_i , and R_i are labor, capital, and land, respectively. And since the limit of the sum of a dummy variable $\tau(x)$ is its integral, we can write

$$e^T = e^{\tau_1 + \tau_2 + \tau_3} = e^{\int \tau(x) dx}, \tag{3}$$

such that in general

$$y = [X_1^{a_1} X_2^{a_2}] e^{\int \tau(x) dx} = [X_1^{a_1} X_2^{a_2}] e^{T(x) + C}, \tag{4}$$

which resembles, but is *not identical* to, Romer (1989, S76-S77). Taking the natural logarithms of both sides of (4) above gives

$$\ln y = a_1 \ln X_1 + a_2 \ln X_2 + \int \tau(x) dx = a_1 \ln X_1 + a_2 \ln X_2 + T(x) + C. \tag{4'}$$

Given (3), average object- productivity and idea-productivity are

$$\begin{aligned}
\ln y^* &= a_2 \ln x_2 + [\int \tau(x) dx - \ln x_1] & [y^* = y/X_1, x_2 = X_2/X_1] \\
\ln y^* &= a_1 \ln x_1 + [\int \tau(x) dx - \ln x_2] & [y^* = y/X_2, x_1 = X_1/X_2]
\end{aligned} \tag{4''}$$

III. Intra-active and inter-active technological change

Because

$$e^{\int \tau(x) dx} = e^{T(x) + C}, \frac{d}{dx} [e^{\int \tau(x) dx}] = \frac{d}{dx} [e^{T(x) + C}] = \tau(x) \Rightarrow d[e^{\int \tau(x) dx}] = d[e^{T(x) + C}] = \tau(x) dx,$$

it follows that partial differentiation of (4) gives resource elasticities as

$$\begin{aligned}
\xi_{X_1} &\equiv \frac{\partial \ln y}{\partial \ln X_1} = a_1 + e^{\tau_1(x)} \cdot \Delta \tau(x) = 0 \quad [\Delta \tau(x) = d\tau(x)/dX] \\
\xi_{X_2} &\equiv \frac{\partial \ln y}{\partial \ln X_2} = a_2 + e^{\tau_2(x)} \cdot \Delta \tau(x) = 0 \quad [\Delta \tau(x) = d\tau(x)/dX] \\
\xi_{\tau_1(x)} &\equiv \frac{\partial \ln y}{\partial \tau_1(x)} = e^{\int \tau(x) dx} [1 + \Delta \tau_1(x)] = 0 \quad [\Delta \tau_1(x) = \tau_1(x) dX \cdot e^{\int \tau(x) dx}] \\
\xi_{\tau_2(x)} &\equiv \frac{\partial \ln y}{\partial \tau_2(x)} = (\Delta \tau_1(x))^2 = 0 \quad [\Delta \tau_2(x) = \tau_2(x) dX \cdot e^{\int \tau(x) dx}] \\
\xi_{\tau(x)} &\equiv \frac{\partial \ln y}{\partial \tau(x)} = \Delta \tau(x) [e^{\tau_1(x)} + e^{\tau_2(x)}].
\end{aligned} \tag{5}$$

In (5) note that X_i are non-stochastic (exogenous) while $\tau_i(x)$ are stochastic so that \int disappears in the former but not in the latter. So, setting $\partial \ln y / \partial \ln x_i = \partial \ln y / \partial \tau_i(x) = 0$ and solving for $\tau_i(x)$ leads to

$$\begin{aligned}
\tau_1(x) &= \ln \left[\frac{e^{\int \tau(x) dx} (1 + \Delta \tau_1(x)) - a_1}{\Delta \tau(x)} \right] \\
\tau_2(x) &= \ln \left[\frac{(\Delta \tau_1(x))^2 - a_2}{\Delta \tau(x)} \right].
\end{aligned} \tag{6}$$

With (5) and (6) in hand we can find the *composite technology* (e^T) as

$$e^T = \int \tau(x) dx = \ln \left[\frac{a_1 + \tau_1(x) \Delta \tau(x)}{1 - \Delta \tau_1(x)} \right] \Rightarrow T(x) = \ln \left[\frac{a_1 + \tau_1(x) \Delta \tau(x)}{1 - \Delta \tau_1(x)} \right] - C. \tag{7}$$

Eq. (7) seems to indicate that the resources of U_2 (ideas) are not important determinants of technological change. Not so, the expression only appears that way because deriving $\tau_1(x)$ assumed $\tau_2(x)$ is constant and vice versa. In truth $\tau_2(x) = f(\Delta \tau_1(x), a_2) \Rightarrow \tau(x) = f(\tau_i(x), a_i)$. In fact, $\tau_3(x) = \tau(x) - \tau_1(x) - \tau_2(x)$. Hence, given $\tau(x)$ it is a matter of standard theory to obtain the level of X_i^* associated with a given level of isoquant y^0 - that is not so hard to do. What is

challenging to demonstrate is the shape of the isoquant given a shifting $\tau(x)$ - but the assertion is a separate investigation altogether. Also unique here is that setting $\xi_{x_1} = \xi_{x_2} = 0$ and solving for $\Delta \tau(x)$ gives

$$\Delta \tau(x) = \frac{a_1 - a_2}{e^{\tau_1(x)} - e^{\tau_2(x)}} = \frac{MP_{X_1}^0 - MP_{X_2}^0}{e^{\tau_1(x)} - e^{\tau_2(x)}}, \quad (8)$$

where MP_i^0 are conventional marginal products, and $\Delta \tau(x)$ is technological change associated with changing universes from U_1 to U_2 . These types of technological shifts are described in Amavilah (1998) and Amavilah and Newcomb (2004). They suggest that moving to one universal state requires abandoning another altogether. This was indeed the early understanding of the industrialization process where an economy moves out of agriculture and mining into manufacturing and then into services, leaving behind a better standard of living on average along with ghost mining towns, for example, as interactive linkages between universes first weaken and eventually disappear. Of course, this result is not entirely improbable (see Amavilah, 2005).

In the present case linkages need not weaken; MP_i are variable, i.e.,

$$MP_{X_i} = \frac{y \cdot \xi_{X_i}}{X_i} = X_j^{a_j} e^{\int \tau(x) dx} [a_i + \Delta \tau(x)]. \quad (9)$$

Hence the variable intra-universal and inter-universal marginal rates of resource transformation can be approximated by

$$\lambda_{i,j} = \xi \cdot x_i \quad [\xi = \xi_{X_i} / \xi_{X_j}, \quad x_i = X_i / X_j], \quad (10)$$

and intra- resource and inter- resource elasticities of substitution (η) are roughly

$$\eta = \xi \cdot \frac{dx}{d\lambda}. \quad (11)$$

Note that (10) and (11) are mathematically vague; whereas tuition demands clarity, intuition permits vagueness as a substitute for flexibility because while X_2 may be a close substitute for or complement of X_1 , X_1 can be a poor substitute for X_2 but just as a good complement. Example: Human capital can

substitute raw labor; raw labor, while a good complement of, is a poor substitute for, a surgeon in the operating room. Moreover, because ξ_{X_i} are variable, careful calculations show variable scale elasticity as

$$\epsilon = \xi_{X_1} + \xi_{X_2} + \xi_{\tau(x)} = a_1 + a_2 + 2\Delta\tau(x)[e^{\tau_1(x)} + e^{\tau_2(x)}] = MP_{X_1}^0 + MP_{X_2}^0 + 2\Delta\tau(x)[e^{\tau_1(x)} + e^{\tau_2(x)}] \quad (12)$$

Eq. (12) clearly suggests that intra-active and inter-active economies are subject to increasing returns to scale, because even if $a_1 + a_2 < 1$, $\forall \tau_i(x) \geq 0$, $\frac{d^2}{dx^2} e^{\tau_i(x)} > 0$, $\exists \epsilon \geq 1$.

IV. Economic growth with intra-active and inter-active technological change

Differentiating (4) with respect to time gives the proportionate growth rate. However, disregarding resource intra- and inter-actions, however,

$$\dot{y} = a_1 \dot{x}_1 + a_2 \dot{x}_2 + \dot{A}, \quad (13)$$

where \dot{A} is either Hicks-Solow, Harrod-Domar neutral rate of technical change (Thirlwall, 1978, Choi, 1983), or Verdoorn-Arrow learning effect (Arrow, 1962), and the dot indicates the growth rate of the variable over which it stands. Considering resource intra- and inter-actions

$$\begin{aligned} \dot{y} &= [a_1 + e^{\tau_1(x)} \cdot \Delta\tau(x)] \dot{x}_1 + [a_2 + e^{\tau_2(x)} \cdot \Delta\tau(x)] \dot{x}_2 + [\Delta\tau(x)(e^{\tau_1(x)} + e^{\tau_2(x)}) \dot{\tau}(x)] \\ &= \xi_{X_1} \dot{x}_1 + \xi_{X_2} \dot{x}_2 + \xi_{\tau(x)} \dot{\tau}(x) \end{aligned} \quad (13')$$

So, “why do some countries produce so much more output per worker than others?”, asks Hall and Jones (1999). Part of the answer is: *because some economies have stronger resource intra- and inter-actions than others and are therefore predisposed to economies of scale*. In fact, intra- and inter-active economies would produce twice as much output as others, and their rates of growth are high because of it - a result not unlike one Amavilah (2005) arrives at in slightly different context.

V. Concluding summary: Where can we find data for this thing?

Paul Romer’s notion of idea and object gaps (or lack thereof) as sources of, and/or constraints to, economic growth has enriched economic growth theory enormously! So did WA Lewis’s division of productive resources into factors and forces. Although Romer acknowledges important interactions involving the flow of ideas between developing and industrialized countries via multinational

corporations, both Romer and Lewis are not explicit about intra- and inter-actions among factors that are essential to technological change. In their extension of Romer, Graca, Jafarey, and Philippopoulos (1995) characterize interactions between human capital (idea) and physical capital (object) in an endogenous framework. The results of their characterization indicate that dynamic economic growth depends increasingly on ideas as the level of development increases. By extension, the brief analysis of the paper argued for intra- actions among objects and ideas on the one side, and inter-actions among objects and ideas on the other hand. Then technological change becomes the *integrand* of the “areas” of resource intra- and inter-actions. Taking this view economies with strong positive resource intra- and inter-actions produce more output than others, and their growth rates are better because of it. Romer (undated) is correct “that economic growth springs from better recipes, not just from more cooking” (page 2 of 5). However, the rate of growth and quality of the growth of the output of a fruitcake depend on the intra-actions among objects (fruits, flour, M&M, etc) and ideas (recipes) as well as the inter-actions among recipes, fruits, and such. One last shot at this: a hunter (primary object), and bow and arrow (intermediate objects) *intra-act* with one another, as well as *inter-act* with a hunter’s knowledge of hunting (idea) in order to produce a game kill. Admittedly modern objects, ideas, and accumulation via investment are more sophisticated than making a game kill. However, the production of a supermaterial, and even of an idea itself, is no different from the production of a fruit cake or a game hunt per se. The difference is in the ratios of object-object and idea-idea intra-actions, on the one side, and object-idea inter-actions on the other side. Hence, one obvious research implication of this analysis is that models that overlook resource intra-actions and inter-actions underutilize powerful aspects of endogenous growth theory. Unfortunately for now the policy implications have to wait empirical tests of the ideas espoused in this paper.

But one would ask: what are the necessary variables and where does one find the data? This is a good question, and like all good questions also a difficult one. However, chief among the objects (X_1), both Lewis and Romer would include fixed and intermediate inputs, such as “raw” labor (L_1), fixed capital LESS depreciation (K_1), and land (R_1) in the classical sense of “gift of Nature”. The intra-actions among these “classical, original” inputs represent (a Solow-like) technological change (τ_1). Ideas or forces would include human capital ($L_2 \equiv H$) first and foremost. Second, they would include what Taylor (2000) calls fluid capital PLUS depreciation (K_2) à la Hotelling (1925), and finally they would include enhanced land and other natural resources (R_2). The difference between R_1 and R_2 is that the former refers to land as a piece of earth upon which a factory building stands, for example; the latter would include processed and semi-processed commodities such as polished versus diamonds, ex-situ vis-a-vis in-situ crude oil, or tanned leather as opposed to rawhide or even a live cow, for instance. The intra-actions among these “classical reproducible, derived, secondary, or higher” inputs produces a second variety of technological change (τ_2).⁴ But goods and services are neither purely object-based nor purely idea-based. For example, some computer components are best produced where the costs of objects are lowest, others where ideas predominant and cost may be of secondary consideration, and still other computer parts require a good mix of ideas and objects to produce. Inter-actions among objects and ideas lead to a third technological change (τ_3), so that overall

⁴The terms “classical, original” inputs and “classical reproducible, derived” inputs are either from or inspired by Samuelson (1994).

technological change (T) is the sum, and in the limit the integral, of the three technological changes. Then Solow's technical progress (at least as interpreted by Abramovitz, 1979) is T + random error term.

What the preceding statements show is that the problem in implementing the modified Lewis-Romer scheme outlined above is not about the lack of clarity of variable definitions and unavailability of data. Neither is it due to the absence of economies sufficiently intra-active and inter-active to allow for study examples. [Four-year college and university economies would make good study cases for this scheme since the division of factors of production is almost ideal]. The problem is statistical. As Romer (1993) points out quantitative growth economists like the statistical convenience accorded by the assumptions of exogeneity - it make things easy; it is familiar; and it produces elegant results.

Yet I can think of at least one, albeit crude, alternative approach that would permit empirical estimations. First, one can employ a number of triple-variable correlation measures outlined by Pan and Harries (2000) to weed out meaningless and/or other suspicious correlations. Suppose after eliminating those correlations from the original set the following is left

$$y=(L_1 \otimes K_1 \otimes R_1)^a (L_2 \otimes K_2 \otimes R_2)^b (L_1 \otimes K_2 \otimes R_2)^c (K_1 \otimes K_2 \otimes L_2)^d (R_1 \otimes L_2 \otimes K_2)^e, \quad (14)$$

where $a, b, c, d,$ and e are constants, \otimes indicates variable correlations, and L_i, K_i, R_i are the most relevant labor, capital, and land inputs on the basis of a Pan-Harris triple-variable correlation matrix (see pp. 134-137). To minimize probable statistical difficulties (14) faces assume the following resource constraints:

$$\begin{aligned} L &\equiv L_1^{\alpha_1} L_2^{\alpha_2} \Rightarrow L_1 = (L L_2^{-\alpha_2})^{\frac{1}{\alpha_1}} \\ K &\equiv K_1^{\beta_1} K_2^{\beta_2} \Rightarrow K_1 = (K K_2^{-\beta_2})^{\frac{1}{\beta_1}} \\ R &\equiv R_1^{\gamma_1} R_2^{\gamma_2} \Rightarrow R_1 = (R R_2^{-\gamma_2})^{\frac{1}{\gamma_1}} \end{aligned} \quad (15)$$

Given (15) express (14) in terms of the intensity of ideas in aggregate labor and capital, which, dividing both sides by L (or any other variable of choice) and after careful calculations, gives

$$\ln y = \lambda_0 + \lambda_1 \ell_2 + \lambda_2 \ln k + \lambda_3 \ln k_2 + \lambda_4 \ln r + \lambda_5 r_2, \quad (16)$$

where

$$\lambda_0 = \ln(\text{productivity shock})$$

$$\lambda_1 = \frac{-a\alpha_2 + b\alpha_1 + \alpha_2 c + \alpha_1 e}{\alpha_1}$$

$$\lambda_2 = \frac{a+d}{\beta_1}$$

$$\lambda_3 = \frac{-a\beta_2 + \beta_1 b + \beta_1 c - \beta_2 d + \beta_1 d + \beta_1 e}{\beta_1}$$

$$\lambda_4 = \frac{a+e}{\gamma_1}$$

$$\lambda_5 = \frac{-a\gamma_2 + \gamma_1 b + \gamma_1 c + \gamma_1 d - \gamma_2 e}{\gamma_1},$$

noting that at the aggregate level $\lambda_1 = (a + c) / \alpha_1$. Thus, (14) can be generalized compactly as

$$y = (X_i)^a (X_j)^b (X_i X_j)^c \Rightarrow y^* = x_j^b x_{ij}^c \quad [y^* = Y/X_i, x_j = X_j/X_i, x_{ij} = (X_i X_j)/X_i]. \quad (17)$$

Consequently the growth rate of (17) is

$$\dot{y}^* = b\dot{x}_j + c\dot{x}_{ij}, \quad (18)$$

which appears familiar, but is fundamentally different in content because even if we added \dot{A} (18) \neq (13) ■

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