

BIASED TECHNOLOGICAL PROGRESS AND LABOR FORCE GROWTH IN A DUALISTIC ECONOMY *

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Introduction, 426.—I. The structure of the dual economy, 427.—II. Labor force growth and biased technological progress: comparative statics, 432.—III. Labor force growth and biased technological progress: dynamics, 435.—IV. A numerical experiment, 436.—V. Conclusion, 443.—Appendix A, 445.—Appendix B, 447.

INTRODUCTION

Asian development in the 1970's is likely to take place under conditions quite different from those typical of the past two decades. These changing conditions will have an important influence on the research focus relating to growth and development. This paper examines two such changes. First, the population explosion of the 1940's and 1950's will be transformed into a labor force explosion in the current decade. While an extensive literature has developed on urban employment and labor absorption problems,¹ for the most part the work utilizes partial equilibrium analysis. A more productive approach to an analysis of the impact of the expected labor force explosion requires a general dynamic framework that specifies explicitly the derived labor demand functions in the industrial and nonindustrial sectors, the economy-wide labor supply function, and the process of intersectoral migration. The present paper develops such an analysis. Second, many Asian countries are now introducing high-yielding, fertilizer-responsive seed varieties to an extent reminiscent of earlier Western episodes of Agrarian Revolution. Without exception these agricultural developments are of the labor-using, land-cum-capital-saving type.² Most of the analysis of the

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1. See, e.g., J. Williamson, "Capital Accumulation, Labor Saving, and Labor Absorption Once More," this *Journal*, LXXXV (Feb. 1971), 40-65, and L. Lau and P. Yotopoulos, "Micro-Functions in a Macro-Model: An Application to Agricultural Employment and Development Strategies." Conference on Micro Aspects of Development, University of Illinois at Chicago Circle, Nov. 19-21, 1970.

2. B. F. Johnston and J. Cownie, "The Seed-Fertilizer Revolution and

Green Revolution has dealt with the agricultural sector in isolation. To a large extent that is also true of the research on the impact of labor-saving innovations in the industrial sector. This paper explores the simultaneous impact of biased innovations in both sectors within a general equilibrium framework. The model is closed and consists of an agricultural and an industrial sector, the latter producing both consumption and investment goods. This places the framework in the literature on economic dualism, the most prominent contributions to which have been by Jorgenson³ and Fei and Ranis,⁴ rather than in the literature on Uzawa-type models,⁵ which consist of consumption and capital goods sectors. The latter class of models is better suited to an exploration of theoretical problems of growth in the more advanced industrial economies.

One of our conclusions is that the Asian economies are likely to adjust to the expected labor force explosion in the 1970's far more easily than the conventional literature suggests. Furthermore, we find evidence implying that the presence of biased technical progress may seriously inhibit the rate of both capital accumulation and industrialization without significant improvements in per capita income growth. Finally, the advantages of rapid rates of capital accumulation and technical progress are made much clearer in our model than has been apparent in the sources of growth literature.

The model is briefly developed in Section I and presented in detail in Appendix A. Section II uses comparative static analysis to explore the impact of labor force expansion and biased technological progress in the dual economy; Section III develops the dynamic analysis. This is followed in Section IV by a numerical experiment that utilizes parameters and initial conditions drawn from South-east Asia and, in addition to the issues already raised, critically evaluates the sources of growth methodology.

I. THE STRUCTURE OF THE DUAL ECONOMY

Our approach to model construction is eclectic in that we view dualism as multidimensional. Even though the traditional treatment

Labor Force Absorption," *American Economic Review*, LIX (Sept. 1969), 569-82.

3. D. Jorgenson, "The Development of a Dual Economy," *Economic Journal*, LXXI (June 1961), 309-34.

4. J. Fei and G. Ranis, *Development of the Labor Surplus Economy: Theory and Policy* (New Haven: Yale University Press, 1964).

5. H. Uzawa, "On a Two-Sector Model of Economic Growth," *Review of Economic Studies*, XXIX (Oct. 1961), 40-47, and XXX (June 1963), 105-18.

by Jorgenson and Fei and Ranis, which focuses on a single aspect of dualism — production conditions — represents a very significant contribution to the characterization of development, the impact of alternative dualistic features constitutes the next logical advance to the theory. Namely, in accordance with the extensive descriptive literature, our model incorporates both differing sectoral demographic and demand behavior, as well as variations in production conditions. While each of those three factors is empirically established as a dualistic attribute of the developing countries, their geographic-specific locus (urban-rural) and their joint interaction appear to us to be potentially potent elements in models of growth and structural change. The present model incorporates for the first time in a single formal framework each of these widely discussed dualistic features of development.

In addition to our multidimensional approach to dualism, in two fundamental respects we depart from the traditional treatment of production conditions. First, in contrast to the usual treatment, we have elected to introduce purchased capital inputs as an element in agricultural production. We feel our approach to be defensible. It explicitly introduces a key policy decision widely debated in the developing countries — investment in industry or agriculture? It recognizes the historical importance of purchased intermediate and primary inputs to the agricultural sector as successful development takes place. Finally, it provides a theoretical structure more akin to the neoclassical growth literature, thus permitting an evaluation of the relative importance of the dualistic specifications on aggregate growth and structural change.⁶ Second, since both of our sectoral production functions contain similar arguments — capital and labor — our conception of dualistic behavior focuses on differing production *parameters*: namely, differences in the possibilities for factor substitution.

6. The decision to include capital has necessitated the omission of land. While we recognize that the quality and character of land in a low-income economy may have an important effect on production, economic theory provides few guidelines explaining either the rate of land expansion or quality improvement. Most commonly, land is treated as fixed. On the supply side, this assumption merely provides diminishing returns to other productive factors, a feature that could be insured simply by assumption. On the demand side, even though the property earnings could influence savings and consumption patterns, again the literature tends to attenuate or eliminate this potential role. For example, both the Fei-Ranis and the Jorgenson models assume that the marginal propensity to save out of property income is zero. Since we cannot identify a specification of land augmentation or a hypothesis on property income savings that commands significant empirical support, we have elected at this stage to omit land as an argument in production.

We write the production function in industry ($i=1$) and agriculture ($i=2$) as

$$Q_i(t) = F^i[x(t)K_i(t), y(t)L_i(t)] \quad (i=1, 2),$$

where F^i is subject to constant returns to scale and diminishing marginal rates of substitution; $K_i(t)$ and $L_i(t)$ represent sector stocks of currently employed capital and labor; $x(t)$ and $y(t)$ are technical progress variables; and $x(t)K(t)$ and $y(t)L(t)$ are efficiency factor stocks. In an attempt to capture the hypothesis of "technological dualism," we assume that substitution possibilities are more limited in the urban-industrial sector: that is, $0 < \sigma_1 < 1 \leq \sigma_2$, where σ_i is the elasticity of substitution. One of our prime concerns is to evaluate the significance of biased technological progress in both industry and agriculture. Considerable evidence has been collected, especially for Asian countries, that supports the generalization that technical change is labor-saving in industry⁷ and labor-using in agriculture.⁸ Theoretical support for this has also been accumulating. The "induced innovation hypothesis," extended by Kennedy⁹ and Ahmad,¹ suggests that under realistic assumptions labor-saving innovations are precipitated by historically rising wage-rental ratios. A recent study of nineteenth- and twentieth-century Japanese and American agriculture by Hayami and Ruttan lends support to this hypothesis.² To the extent that industrial technologies are imported from abroad while agricultural technologies (IR-8, Mexican dwarf varieties) are locally developed, a theoretical explanation of the factor-saving bias in developing economies can be readily derived.

The nature of the bias can be conveniently analyzed in terms of the well-known Hicksian concept of neutrality. Technological progress is neutral if it leaves the capital-labor ratio unaltered at a constant ratio of factor prices. The factor-saving bias, $B(t)$, is defined as the proportionate rate of change in the marginal rate of factor substitution:

$$B_i(t) = \frac{\partial F_{K^i}^i}{\partial t} \cdot \frac{1}{F_{K^i}^i} - \frac{\partial F_{L^i}^i}{\partial t} \cdot \frac{1}{F_{L^i}^i} \quad (i=1, 2),$$

7. Williamson, *op. cit.*

8. T. Watanabe, "Economic Aspects of Dualism in the Industrial Development of Japan," *Economic Development and Cultural Change*, IV (April 1965), 293-312, and Johnston and Cownie, *op. cit.*

9. C. Kennedy, "Induced Bias in Innovation and the Theory of Distribution," *Economic Journal*, LXXIV (Sept. 1964), 541-47.

1. S. Ahmad, "On the Theory of Induced Invention," *Economic Journal*, LXXVI (June 1966), 344-57.

2. Y. Hayami and V. Ruttan, "Factor Prices and Technical Change in Agricultural Development: The United States and Japan, 1880-1960," Staff Paper P69-19, Department of Agricultural Economics, University of Minnesota (July 1969).

where $F_K^i = F_K^i x(t)$ and $F_L^i = F_L^i y(t)$ are the respective marginal products of capital and labor. For any given factor ratio, technological progress is labor-saving in the Hicksian sense if $B_i(t) > 0$, and capital-cum-land-saving if $B_i(t) < 0$. It is well known that the sectoral bias depends on both the value of σ_i and the relative rates of factor augmentation.³ If we assume that $x(t)$ and $y(t)$ grow at exogenously given rates, λ_K and λ_L , respectively, then

$$B_i(t) = \frac{[\lambda_L - \lambda_K] [1 - \sigma_i]}{\sigma_i}.$$

Since it is generally agreed that technological progress is labor-saving in industry (for developing economies, at least) and capital-cum-land-saving in agriculture, and given our dualistic specification on σ_i , then it follows that $[\lambda_K - \lambda_L] < 0$.

The intensity of technological progress measures the output-raising effects given a fixed factor ratio:

$$R_i(t) = \frac{F_K^i x(t) K_i(t)}{Q_i(t)} \frac{dx(t)}{dt} \cdot \frac{1}{x(t)} + \frac{F_L^i y(t) L_i(t)}{Q_i(t)} \frac{dy(t)}{dt} \cdot \frac{1}{y(t)}.$$

Amano⁴ and Fei and Ranis⁵ have shown that

$$R_i(t) = \lambda_K \alpha_i(t) + \lambda_L [1 - \alpha_i(t)] \quad (i=1, 2),$$

where $\alpha_i(t)$ is the current elasticity of output with respect to capital. $R_i(t)$ is a weighted average of the factor augmentation rates, the weights being the input elasticities of output. There is an important consequence of our assumptions regarding $B_i(t)$ and σ_i that seems especially relevant to the Asian economies of the 1970's. With the simplifying assumption that the factor-specific rates of augmentation are the same in the two sectors, it follows that $R_2(t) > R_1(t)$ if the output elasticity of capital is greater in industry. While this result seems consistent with contemporary Asian experience and the impressive agricultural productivity improvements presently taking place there, it may have less applicability historically.

The second element of dualism in our model is demographic. It has been widely observed that in developing economies the natural rates of population growth are higher in rural areas. Incorporating

3. J. Fei and G. Ranis, "Innovational Intensity and Factor Bias in the Theory of Growth," *International Economic Review*, VI (May 1965), 182-98.

4. A. Amano, "Neoclassical Biased Technical Progress and a Neoclassical Theory of Economic Growth," this *Journal*, LXXVIII (Feb. 1964), 129-38.

5. "Innovational Intensity and Factor Bias," *op. cit.*

this hypothesis into our model, we can express the overall rate of labor force growth as

$$\frac{dL(t)}{dt} \cdot \frac{1}{L(t)} = n_1 u(t) + n_2 [1 - u(t)],$$

where the economy-wide rate of population growth is endogenously determined and is influenced by the level of urbanization. While there is a long gestation period between changes in population growth rate and changes in labor force growth rates, our current interest is in an analysis of the expected Asian labor force explosion that will manifest itself fully in the present decade.

The final dualistic feature of the model appears in the demand system. We hypothesize that demand behavior is different between sectors, as reflected in taste parameters, and that consumption behavior in both sectors can be described by a simplified Stone-Geary linear expenditure system. The worker's demand system is therefore given by

$$\begin{aligned} \frac{D_{1j}(t)}{L_j(t)} &= \frac{\beta_{1j}}{P(t)} \{y(t)w_j(t) - \gamma\}, \\ \frac{D_{2j}(t)}{L_j(t)} &= \beta_{2j} [y(t)w_j(t)] + [1 - \beta_{2j}] \gamma, \end{aligned}$$

where D_{ij} is the total amount of the i^{th} good consumed by the labor force in j , $0 < \beta_{ij} < 1$ and $\beta_{1j} + \beta_{2j} = 1$, and $w_j(t)$ is the current wage of efficiency labor in the j^{th} sector. Dualism in consumption behavior is reflected by the specification $(\beta_{11} - \beta_{21}) > (\beta_{12} - \beta_{22}) > 0$; that is, "Engel effects" are operative throughout the economy, but urban workers have a higher relative preference for urban goods. As with demographic dualism, demand dualism may not persist into very high levels of industrialization. We only assert its importance for low-income economies. Part of the appeal of this formulation for the economies described is the existence of the parameter γ_{ij} , interpreted as the minimum acceptable amount of the i^{th} commodity required per laborer in the j^{th} sector. For simplicity, only foodstuffs are treated as essential wage-goods; $\gamma_{1j} = 0$ and $\gamma_{2j} = \gamma > 0$.

Other less novel elements of our model's structure are summarized in a complete model statement in Appendix A. We invoke the traditional hypothesis that only property income recipients save and that their savings rate is a constant proportion of property income. Following Jorgenson, we also adhere to the neoclassical hypothesis of marginal product pricing, thus departing from the labor surplus tradition. Finally, full factor utilization is assumed. The static equilibrium model is a system of fifteen equations (one of

which is redundant), fourteen endogenous variables, and four exogenous variables. However, in exploring the impact of population growth and technical change in the system, the analysis is most conveniently handled in per capita terms. We therefore define and utilize the following variables:

$$\begin{aligned}
 q_i(t) &\equiv \frac{Q_i(t)}{y(t)L_i(t)} && \text{output per unit of efficiency labor} \\
 k(t) &\equiv \frac{x(t)K(t)}{y(t)L(t)} && \text{efficiency capital per efficiency labor} \\
 \omega(t) &\equiv \frac{w(t)}{r(t)} && \text{wage-rental ratio} \\
 z_{ij} &\equiv \frac{D_{ij}(t)}{L_j(t)} && \text{per capita wage earner's demand} \\
 \phi(t) &\equiv \frac{I(t)}{K(t)} && \text{gross investment rate.}
 \end{aligned}$$

A statement of the model in per capita terms is also presented in Appendix A.

II. LABOR FORCE GROWTH AND BIASED TECHNOLOGICAL PROGRESS: COMPARATIVE STATICS

Our prime interest is to explore the implications of an expected sharp increase in labor force growth in the 1970's for the dualistic economy, and further to isolate the impact of an increased labor-saving bias in industry and labor-using bias in agriculture, which appear to be increasingly important characteristics of the developing nations. Even though those issues are both appropriately analyzed in a framework of dynamic analysis, it is useful first to consider briefly the comparative static properties of our model. This will permit the reader to identify in summary fashion the main analytical features of the economy, and as a result, to obtain a better grasp on the operation of the dynamic system that occupies the main thrust of this study.

After considerable manipulation of the equations of the static equilibrium model, (A.22) – (A.29), it can be shown that the entire system can be expressed as a unique, monotonic relationship between the efficiency capital-labor ratio and the wage-rental rate; thus,

$$k = \psi(\omega) \equiv k_2(\omega) + \frac{\{yf_2[k_2(\omega)] - z_{22}(\omega)\}[k_1(\omega) - k_2(\omega)]}{yf_2[k_2(\omega)] + z_{21}(\omega) - z_{22}(\omega)}.$$

If we impose the realistic restriction that production in industry is

relatively capital intensive, it can also be demonstrated that the model possesses a solution; moreover, assuming $\sigma_2 \geq 1$, then the solution is both unique and stable.⁶

In the process of examining these qualitative properties of the model, five key features of the economy have been derived. A listing of the features both provides the building blocks for analyzing the comparative static economy, and also demonstrates the basic conformity of our system with the main conclusions forthcoming from the literature on dualistic, neoclassical models.

First, $d\omega_i/dk_i > 0$; the sectoral wage-rental ratio is a monotonic, increasing function of the sectoral efficiency capital-labor ratio. As production becomes more (less) capital intensive, the relative reward of labor (capital) increases. That result is forthcoming in all neoclassical models where production functions are well behaved.

Second, $d\phi/d\omega < 0$; the rate of capital stock growth (*gross* of depreciation requirements) is a decreasing function of the wage-rental ratio. Since total investment is determined in our model by the source distribution of income, an increase in the relative reward to labor, the low (zero) savers, will decrease the rate of capital formation.

Third, $dP/d\omega \leq 0$ when $[k_1(\omega) - k_2(\omega)] \geq 0$; the terms of trade is a decreasing (increasing) function of ω when capital intensity in industry is greater (less) than that in agriculture. This result demonstrates that, if and when factor reversal occurs, the movement in the terms of trade changes direction. There is considerable support for the view that the industrial sector is more capital intensive than the agricultural sector, particularly at low levels of per capita income. We have adopted this specification throughout our analysis. As a result, the terms of trade in our model will always move inversely with the wage-rental ratio. As labor becomes relatively more expensive, the price of industrial goods declines, since labor is used in relatively smaller proportions in this sector.

Fourth, $dz_{ij}/d\omega > 0$; per capita consumer demand for both urban and rural goods moves directly with the wage-rental ratio. Since an increase in the wage-rental ratio implies an increase in each consumer's (wage earner's) income, then the demand for all consumption goods receives a positive stimulus. Finally, $du/d\omega \leq 0$ when $[k_1(\omega) - k_2(\omega)] \geq 0$; urbanization moves inversely with the wage-

6. The standard procedures for examining existence, uniqueness, and stability are employed. For a detailed discussion and demonstration of the above conclusions, see A. Kelley, J. Williamson, and R. Cheetham, *Economic Dualism in Theory and History* (Chicago: University of Chicago Press, forthcoming 1972).

rental ratio in the case where urban goods are produced with relatively capital-intensive techniques. As the relative cost of labor increases, substitution against this factor takes place in both sectors. Given the relative ease of substitution in agriculture, more labor is retained and thus the rate of urbanization diminishes.

Consider now the impact of technical progress in our economy. The comparative static analysis is summarized in Table I, where biased technical change is captured by $d(x/y)$. We have already established that labor-saving technical change in industry and labor-using technical change in agriculture implies that $\lambda_L - \lambda_K > 0$. What would be the impact of a once-over fall in x/y given fixed physical stocks of factors, that is, the impact of labor-saving technical change in industry coupled with labor-using technical change in agriculture — a very realistic characterization of present innovations in developing economies? Since the physical capital-labor ratio remains unchanged, then technical change will reduce the efficiency capital-labor ratio; that is, $dk = k \left[\frac{dx}{x} - \frac{dy}{y} \right] < 0$. The resulting impact will be a reduction in the wage-rental rate because $\frac{\partial \psi}{\partial \omega} > 0$. Thus, the relative price of labor declines, contrary to the conclusion that development economists have reached in the recent literature.⁷ The fall in ω results in a decline in capital-labor ratios in both sectors and, together with $d(x/y) < 0$, a decline in k_i . A re-

TABLE I
RESULTS OF COMPARATIVE STATIC ANALYSIS

	dk_1	dk_2	du	$d\omega$	dP	dz_{11}	dz_{12}	dz_{21}	dz_{22}	$d\phi$
$d(x/y)$	+	+	+	+	-	?	?	?	?	-
dk	+	+	+	+	-	+	+	+	+	-

duction in the marginal productivity of efficiency labor in each sector follows, but the change in the marginal product of labor is ambiguous. While the decline in the marginal productivity of efficiency labor tends to lower the wage paid to laborers, this is offset by the rise in y so that the net change on wage income $y\omega f'_2(k_2)$ is ambiguous. On the other hand, the increase in the marginal productivity of efficiency capital gives rise to an increase in the capitalists' in-

7. Johnson and Cownie, *op. cit.*

come and a corresponding rise in investment demand per unit of capital. The effect upon labor absorption rates in industry and the level of urbanization is, of course, negative.

An increase in the physical stock of labor relative to capital has the same effect as an increase in $(\lambda_L - \lambda_K)$ in that k falls, given no change in x and y . But here we know with certainty that per capita consumption levels will fall. Thus, the comparative static analysis predicts the following from the labor force explosion in the 1970's combined with the increased labor-saving and labor-using character of technological progress, in, respectively, industry and agriculture: a decline in the relative price of efficiency labor, a decline in levels of urbanization as labor is redistributed to rural activities, but, as we have seen, a rise in ϕ and the rate of accumulation.

III. LABOR FORCE GROWTH AND BIASED TECHNOLOGICAL PROGRESS: DYNAMICS

Since our model abstracts from questions of optimal intertemporal behavior, the discussion of the impact of labor force growth and biased technological progress that follows considers feasible, rather than optimal, patterns of long-run growth. The dynamic behavior of the dual economy is described by

$$(1) \quad \frac{dk(t)}{dt} \cdot \frac{1}{k(t)} = \phi(t) + [n_2 - n_1]u(t) - [\delta + n_2 + \lambda_L - \lambda_K].$$

The ratio of gross investment to the capital stock is given by $\phi(t) = x(t)f'_1[k_1(\omega(t))]$ and $u(t) = u[\omega(k(t))]$. We have just shown that an increase in technological progress and an increase in the labor force will result in a downward pressure on the wage-rental rate. In the dynamic economy this effect will be further reinforced by a fall in $u(t)$ with the resulting rise in $n(t)$. The first-order effect of the rise in $(\lambda_L - \lambda_K)$ or n_i , then, is to suppress $\frac{dk(t)}{dt} \cdot \frac{1}{k(t)}$, but since $u(t)$ will also diminish, further increases in the rate of labor force growth are forthcoming.

While we have already explored the impact of technological progress on $\phi(t)$, it is useful to repeat the results in a different way. We can readily derive

$$\frac{d\phi(t)}{dt} \cdot \frac{1}{\phi(t)} = \lambda_K - [1 - a_1(t)] \frac{d\omega(t)}{dt} \cdot \frac{1}{\omega(t)}.$$

With increased labor force growth, $\frac{d\omega(t)}{dt}$ is negative and $\frac{d\phi(t)}{dt}$

is positive. That is, the positive impact on capital accumulation partially offsets the retarding influence of accelerated labor force growth on $k(t)$ growth. Therefore, the overall effect of the labor force explosion on $\frac{dk(t)}{dt} \cdot \frac{1}{k(t)}$ and growth rates unfortunately cannot be determined without specific restrictions on parameters and initial conditions. Similarly, if there is only labor-augmenting technical change (that is, $\lambda_K=0$), then the impact on $\frac{dk(t)}{dt} \cdot \frac{1}{k(t)}$ is again uncertain.

IV. NUMERICAL EXPERIMENT

4.1. The Impact of Labor Force Growth and Biased Technological Progress in the Dual Economy

Since the primary purpose of this paper is to obtain quantitative insight into the likely effects of the increased bias in technological progress and increased labor force expansion on the growth of Asian economies in the 1970's, and given the difficulty of determining with qualitative analysis the nature of the response of $k(t)$ to increases in n_i and $(\lambda_L - \lambda_K)$, it seems appropriate to turn next to a numerical experiment relevant to these economies. The initial conditions and parameter values assumed in the simulation are presented in Appendix B. They are typical of Southeast Asian economies; in most cases they have been estimated directly from Philippine data. The economy is agrarian in orientation; 70 percent of the labor force is employed in agriculture and more than half of gross national product originates there. In spite of significant population pressure, with a population growth rate of 2.7 percent, the economy is able to maintain an initial gross savings rate of about 15 percent. Technical change is positive and labor augmenting, conforming to Philippine experience since the 1950's. The model used in the simulation is a revised version of the one analyzed above in that we now allow for capitalist consumption. The revised model is formally stated in Appendix A, equations (A.1)–(A.3), (A.5)–(A.10), (A.13), (A.14), (A.15), and (A.16)–(A.21).

The simulation itself has been discussed at length in an earlier paper where its striking similarity to Japanese historical experience during the Meiji period was observed.⁸ However, our interest here

8. A. Kelley, J. Williamson, and R. Cheetham, "Growth with Dualism in Demand and Production, and Biased Technical Change," Social Systems Research Institute, EDIE 6931, The University of Wisconsin (August 1969). See

is less in rewriting Asian economic history and more in exploring the response of the economy to once-over changes in the technological bias and in labor force growth. This issue is explored through sensitivity analysis of the demographic and technical progress parameters. Our method is to compute and analyze elasticities of the model's key variables with respect to changes in specified parameters.⁹ These structural elasticities permit us to evaluate the quantitative significance of changes in the key parameters on the economic performance of the dual economy, where our main focus will be on per capita GNP growth, urbanization, the industrial output share, and capital stock growth.

4.2. Labor Force Growth

Since the issue of "labor force explosion" has attracted considerable interest of late, consider first an examination of n_1 and n_2 . In a comparative static framework, an increase in n implies a decrease in the capital-labor ratios; the wage-rental ratio tends to diminish; and as a result, the efficiency capital-labor ratios decline in *each* sector. Given the greater ease of factor substitution in agriculture, the level of urbanization diminishes and the price of industrial goods tends to rise. The ratio of gross savings to the capital stock increases, however, since a decline in the efficiency capital-labor ratio results in an increase in $f'_1[k_1(t)]$.

Table II, which presents the structural elasticities for both urban and rural population growth, provides the basis for two immediate generalizations. First, without exception, an increase in the labor force growth rate tends to exert its primary impact during the first two or three decades. In the case of per capita GNP growth, for example, the dramatic and initial adverse impact is significantly dissipated over time; by the middle of the period, the elasticity has declined from 0.557 to 0.146. The opposite trend, but same pattern,

also Kelley, Williamson, and Cheetham, *Economic Dualism in Theory and History*, *op. cit.*

9. Let v_i^* = variable at t (e.g., $u(t)$, rates of labor absorption in industry etc.), and θ = demographic or technical change parameter; then

$$\frac{\partial v_i^*(\theta)}{v_i(\theta)} \cdot \frac{\theta}{\partial \theta} = \epsilon_{v_i}(\theta)$$

is the structural elasticity measuring the percentage response of v_i^* to a once-over change in θ . These are called "structural elasticities." While the use of ϵ permits us to evaluate the quantitative significance of parameter changes on the economic performance of the dual economy, we should emphasize that the *total* impact of the technical progress or demographic parameter depends not only on the sensitivity of the system to changes in θ , but also on the rate at which θ is likely to change through time.

TABLE II
 STRUCTURAL ELASTICITIES
 URBAN (n_1) AND RURAL (n_2) POPULATION GROWTH

Variable	Value of the elasticity at year —				
	10	20	30	40	50
1. Per capita GNP growth rate					
n_1	-0.557	-0.314	-0.146	-0.091	-0.092
n_2	-1.178	-.376	-.372	-.218	-.100
2. Level of urbanization					
n_1	-.032	-.058	-.074	-.084	-.092
n_2	-.110	-.200	-.234	-.250	-.250
3. Industrial output share					
n_1	-.016	-.027	-.027	-.028	-.027
n_2	-.050	-.110	-.088	-.082	-.076
4. Capital stock growth					
n_1	-.122	.003	.104	.142	.148
n_2	.024	.400	.323	.361	.389

is experienced in urbanization and the industrial output share. Second, growth in the dual economy is far more sensitive to variations in the "natural" rate of labor force growth in rural than in urban areas. This result, of course, will always be produced in an economy with low initial levels of urbanization.

The finding that increased rates of population growth will exert a negative impact on per capita output expansion is not surprising; this result is forthcoming from most general equilibrium models of growth. Of much greater interest and importance, however, is the observation that the negative influence may be attenuated through time as the result of the impact of labor force growth on factor shares and capital accumulation. In particular, a notable feature of the dualistic model is that a rise in n_i also *increases* the rate of capital accumulation since

$$\phi(t) = \frac{I(t)}{K(t)} = sx f'_1[k_1(t)],$$

$f''_1[k_1(t)] < 0$ and $dk_1(t) < 0$. The differential equation (1) reveals explicitly the competing influences of an increase in labor force growth rates on $\frac{dk(t)}{dt} \cdot \frac{1}{k(t)}$. Since $d\phi(t) > 0$, the negative impact of a rise in labor force growth rates on $\frac{dk(t)}{dt} \cdot \frac{1}{k(t)}$ is somewhat offset. Due to the greater ease of factor substitution in the agricul-

tural sector, the rise in n_i results in a much smaller impact on $k_1(t)$ than $k_2(t)$. Nevertheless, the offsetting influence of $\phi(t)$ increases dramatically in early phases of growth, and the effect of the "labor force explosion" has an *increasingly* positive influence on capital accumulation over time. Thus, *the rate of urbanization (and industrialization) is sharply curtailed in the first two decades of experience with higher rates of labor force growth, but the impact becomes negligible thereafter.*

The impact of an increase in "natural" labor force growth rates on per capita GNP growth can now be readily isolated. We know that, while urbanization levels will be negatively affected, the increasing magnitude of this influence diminishes over time. Thus, even though the overall population growth rate will rise, its rate of increase will decline significantly. For this reason the adverse impact of an increase in the population growth rate on per capita GNP growth should also diminish. Now since per capita GNP is stimulated in the early decades by a rapid rise in $\phi(t)$, it follows that the negative impact of the labor force explosion in the 1970's on labor productivity growth should diminish rapidly after the first decade or so.

These results underscore the utility of the general methodology we have employed. If one is to extend the analysis of population effects beyond the pessimistic predictions of most partial equilibrium empirical studies and general equilibrium qualitative analyses (where signs alone are considered), it is necessary to take into account the *quantitative* dimensions of the problem with an explicit consideration of the short and the long run. Thus, while our results are consistent with the predicted adverse impact of increased population growth on output expansion, the analysis also suggests that the long-run severity of the problem is not as great as commonly thought; clearly, however, the shorter-run adjustment problems may prove significant indeed.

4.3. Biased Technological Change

We next perform two sensitivity experiments involving the simultaneous variation in the technical progress parameters (λ_L, λ_R) so as to (i) increase the sectoral bias, $B_i(t)$, while holding constant the overall rate of technical change, $R(t)$, e.g., raise (lower) the labor-saving bias in the industrial (agricultural) sector while holding $R_i(t)$ constant; and (ii) raise the rates of technological change in both sectors while holding the bias constant. This approach permits a decomposition of technical change into these two key com-

ponents, thereby facilitating an analysis of the way in which each enters into the dynamic behavior of the growing economy. Although our prime concern is with current Asian experience, there is considerable historical evidence that the rate and bias of technological progress varies significantly in sign and size over time. Watanabe and Fei and Ranis, for example, view the period around 1915 in Japanese history as an "epochal" turning point in the bias (at least in manufacturing);¹ Brown identifies "epochs" in American twentieth-century history centering in the 1920's, where he records a switching from a labor-saving to labor-using bias in the nonfarm sector.²

To hold $R_i(t)$ constant while increasing the bias involves an increase in $y(t)$ and a decrease in $x(t)$. Now $d\left(\frac{x}{y}\right) < 0$ implies a reduction in $k(t)$, $\omega(t)$, and thus $k_i(t)$ as well. It also implies a reduction in urbanization levels and a reduced rate of rural outmigration as a result of agriculture's greater success in raising the labor intensity of production; accordingly, the terms of trade should initially improve for industry. The effect of the increasing labor-saving bias in manufacturing is, of course, to diminish both the rate of labor absorption and labor's share in that sector. Without more restrictive assumptions or numerical analysis, the impact on $\phi(t)$ is uncertain because $f'_1[k_1(t)]$ rises and $x(t)$ falls.

The interesting issue involves the impact of the changing bias on the economy's growth performance. Expression (1) indicates that by holding $R_i(t)$ constant and raising λ_L and lowering λ_K , the increased bias has a negative influence entering through $\phi(t)$ as well as through $[\lambda_L - \lambda_K]$. The structural elasticities reported in Table III show the negative impact to be important. The rate of capital stock growth is diminished throughout (Table III, line 6), although the negative impact is much greater in the earlier phases of growth following an "epochal" change in the bias. Since the rate of urbanization is also attenuated by the increased bias, the overall rate of population growth declines at a lower pace and thus the impact on $k(t)$ increases over time. That is, increasing the bias in technological progress tends to have an increasingly powerful impact on suppressing the rate of growth in $k(t)$ in later phases of growth. Surprisingly, the resulting influence on GNP growth rates and the in-

1. Watanabe, *op. cit.*, and Fei and Ranis, *Development of the Labor Surplus Economy, op. cit.*

2. M. Brown, *On the Theory and Measurement of Technical Change* (Cambridge: Cambridge University Press, 1966).

TABLE III
STRUCTURAL ELASTICITIES
TECHNICAL CHANGE: OVERALL RATE CONSTANT, CHANGE IN BIAS

Variable	Value of elasticity at year				
	10	20	30	40	50
1. GNP growth rate	0.005	-0.000	0.056	0.013	0.025
2. Per capita GNP growth rate	-.000	-.036	.133	-.021	-.001
3. Level of urbanization	-.060	-.120	-.169	-.210	-.242
4. Industrial output share	-.013	-.021	-.024	-.025	-.023
5. Capital-labor ratio	-.070	-.140	-.202	-.256	-.300
6. Capital stock growth	-.245	-.202	-.201	-.115	-.072

dustrial output share is rather small. Nevertheless, the former is affected positively, and the latter negatively throughout. GNP per capita growth, on the other hand, is only significantly diminished in the first decade.

Very different results are forthcoming if the system maintains a constant bias while the intensity of technical change is accelerated (Table IV). Initially, of course, the economy-wide capital-labor

TABLE IV
STRUCTURAL ELASTICITIES
TECHNICAL CHANGE: BIAS CONSTANT, CHANGE IN THE OVERALL RATE

Variable	Value of elasticity at year				
	10	20	30	40	50
1. GNP growth rate	0.270	0.242	0.300	0.316	0.282
2. Per capita GNP growth rate	1.143	.898	1.027	1.042	.926
3. Level of urbanization	0.054	.134	0.215	0.297	.370
4. Industrial output share	.044	.099	.134	.165	.184
5. Capital-labor ratio	.020	.090	.202	.347	.508
6. Capital stock growth	.156	.275	.351	.375	.379

ratio is unaffected. The rate of capital accumulation responds positively to the increased intensity of technical change, especially in early phases of growth. As a result, the economy-wide capital-labor ratio is higher, and increasingly so as development takes place, than at lower rates of technical change. To summarize, an increased labor-augmenting bias in technical change reduces the rate of capital formation, the rate of urbanization and, to a lesser extent, the rate of per capita income growth. In contrast, an increased rate (intensity) of technical change has the opposite effect. Furthermore, an increased labor-augmenting bias inhibits industrialization

while an increase in the economy's intensity of technical change stimulates industrialization.

4.4. Sources of Growth and Capital Formation in the Dual Economy

One further issue of interest remains. Although the simulation itself is not reported in this paper, a key feature of those results can be readily summarized. Average labor productivity growth in industry is approximately 1 percent per annum in the first decade of growth. The residual or the intensity of technical progress, $R_1(t)$, "accounts for" about 0.7 percentage points. Thus, we have recaptured the fundamental paradox of the sources of growth literature: 70 percent of average labor productivity growth is "explained by" technical progress.³ Does it therefore follow that capital formation is also unimportant in our low-income dualistic economy?

This question can best be answered by examining the structural elasticities reported in Table V. There we observe that capital stock and GNP growth rates are significantly influenced by a 1 percent increase in the savings parameter. A 1 percent increase in the savings parameter produces a 2.5 percent increase in capital stock growth rates by the end of the first decade. This result may

TABLE V
STRUCTURAL ELASTICITIES
CAPITALISTS' SAVING RATE

Variable	Value of elasticity at year				
	10	20	30	40	50
1. GNP growth rate	0.684	0.501	0.431	0.081	0.027
2. Per capita GNP growth rate	3.022	2.040	1.709	0.612	0.472
3. Level of urbanization	0.409	0.777	1.017	1.160	1.216
4. Industrial output share	0.191	0.322	0.382	0.392	0.373
5. Capital-labor ratio	0.701	1.349	1.868	2.265	2.539
6. Capital stock growth	2.433	1.767	1.246	0.786	0.458
7. Labor factor share	-0.057	-0.105	-0.116	-0.098	-0.056

3. There are a number of examples of the aggregate production function being applied to developing economies: Chile (A. C. Harberger and M. Selowsky, "Key Factors in the Economic Growth of Chile: An Analysis of Sources of Past Growth and Prospects for 1965-1970," Conference on the Next Decade of Latin American Economic Development, Cornell University, April 20-22, 1966); the Philippines (J. Williamson, "Dimensions of Postwar Philippine Economic Progress," this *Journal*, LXXXIII (Feb. 1969), 93-109); and even Mainland China (T. C. Liu, "The Tempo of Economic Development of the China Mainland, 1945-65," *An Economic Profile of Mainland China*, the Joint Economic Committee, Congress of the United States, Feb. 1967). In the Philippine case, 70 percent of average labor productivity growth is attributable to the "residual," 1955-1965 (Williamson, *op. cit.*, p. 97).

at first seem puzzling. In particular, given the capital-output ratio, the nonlabor income share, and with zero depreciation rates, would not one expect that a 1 percent change in s would produce a like change in the rate of capital formation? In fact, the initial increase in s produces an accelerated decline in labor's share and thus even higher rates of accumulation at the end of the first decade. These cumulative effects are totally ignored in the numerical analyses in the sources of growth literature. In any case, the resulting impact on GNP growth is between 0.6 and 0.7 percent. Given economy-wide factor shares of roughly 50 percent and constant rates of (disembodied) technical progress, this result is consistent with *both* the sources of growth literature *and* the emphasis that savings behavior receives from development economists. Note, however, that per capita income growth is raised by 3 percent! The significance of Nelson's remarks regarding interaction effects now becomes strikingly apparent.⁴ What the sources of growth literature fails to appreciate is precisely how increased savings rates foster industrialization-urbanization and thus a more rapid decline in population growth. Although such interaction effects may be safely ignored in a mature, fully industrialized country, they can hardly be ignored in the dualistic economy.

V. CONCLUSION

In this paper we have constructed a formal model of economic dualism in order to explore the impact of a changed rate and bias in technical progress, and an increased rate of labor force growth, for a typical developing Asian economy. A number of interesting conclusions are forthcoming from our qualitative and numerical analysis.

The advantage of rapid rates of technical change (and capital formation) in developing economies now becomes much clearer than has been apparent in the sources of growth literature. Many of the studies applying aggregate production functions to developing economies have found that technical change "accounts for" a very large share of output growth in Asian and Latin American countries. Our analysis suggests that the contribution of technical change has been underestimated. Rapid rates of technical change also tend to raise achievable rates of capital accumulation and to lower rates of population growth by stimulating urban-industrial development. Our

4. R. Nelson, "Aggregate Production Functions and Medium-Range Growth Projections," *American Economic Review*, LIV (Sept. 1964), 575-606.

results also show that for any given $R(t)$ high rates of labor-augmenting technical change are a definite *disadvantage* to developing economies. Furthermore, the disadvantage increases as the degree of dualism increases, that is, as the value of $\{\sigma_2 - \sigma_1\}$ and $\{n_2 - n_1\}$ increases. These "dualistic" features of underdevelopment are at the heart of the analysis of the impact of technical change on the process of economic growth. The existence of these features of dualism has important implications for the rate of labor absorption and urban "unemployment."

This conclusion does not imply a reduced emphasis on capital formation in the dualistic economy. On the contrary, we have quantified the accumulative impact of increased savings parameters in our economy. We find over a decade the elasticity of per capita income growth to our savings parameter to be in the neighborhood of 2.5.

The presence of biased technical change also has important implications for rates of industrialization and capital accumulation in the dual economy. We find that increases in the bias may tend to inhibit the rate of industrialization and reduce the rate of capital accumulation without appreciable changes in per capita GNP growth. Related to these results is the extent to which labor absorption in the industrial sector is affected: we observe an important retarding influence that accumulates over time. Most developing economies are faced with precisely this bias, and adoption of "modern" industrial techniques is often an explicit policy objective. Yet we find GNP per capita growth rates relatively insensitive to changes in the bias. Presumably, a policy that encourages the adoption of "modern" techniques is based on the belief that per capita GNP will be raised in the long run. Our analysis suggests no such effect, and this questions the wisdom of a policy that favors the introduction of labor-saving technique in industry.

Finally, in terms of our specific model we have shown that pessimism regarding the inability of Asian economies to adjust to the expected labor force explosion in the 1970's may be exaggerated. An increased rate of capital stock growth can be expected after some lag, so that the depressing effect on GNP per capita growth may be only a temporary phenomenon. Our time horizon, however, is somewhat longer than normally entertained: the term "temporary" refers to a decade. In the shorter run, a rise in labor force growth rates by 1 percent may produce a decline in per capita GNP growth rates by more than 1 percent — a problem of serious dimensions.

APPENDIX A

The basic static model is composed of fourteen endogenous variables

$$\{Q_i(t), K_i(t), L_i(t), w(t), r(t), P(t), D_{ij}(t), \text{ and } I(t), \\ (i, j=1, 2)\}$$

and four exogenous variables

$$[K(t) = K, L(t) = L, x(t) = x, \text{ and } y(t) = y].$$

$$(A.1) \quad Q_i(t) = F^i[xK_i(t), yL_i(t)] \quad (i=1, 2)$$

$$(A.2) \quad \frac{D_{1j}(t)}{L_j(t)} = \frac{\beta_{1j}}{P(t)}[yw(t) - \gamma] \quad (j=1, 2)$$

$$(A.3) \quad \frac{D_{2j}(t)}{L_j(t)} = \beta_{2j}yw(t) + [1 - \beta_{2j}]\gamma \quad (j=1, 2)$$

$$(A.4) \quad I(t) = \frac{x}{P(t)}[r(t)K]$$

$$(A.5) \quad w(t) = P(t)F_L^1$$

$$(A.6) \quad w(t) = F_2^2$$

$$(A.7) \quad r(t) = P(t)F_K^1$$

$$(A.8) \quad r(t) = F_K^2$$

$$(A.9) \quad K = K_1(t) + K_2(t)$$

$$(A.10) \quad L = L_1(t) + L_2(t)$$

$$(A.11) \quad Q_1(t) = D_{11}(t) + D_{12}(t) + I(t)$$

$$(A.12) \quad Q_2(t) = D_{21}(t) + D_{22}(t)$$

One of the two commodity market equations can be ignored if at least one $P^*(t)$ exists that satisfies equilibrium conditions.

If we introduce the realistic possibility of capitalist demand for consumer goods, then the above system can be modified by replacing (A.4), (A.11), and (A.12) with (A.13), (A.14), and (A.15):

$$(A.13) \quad I(t) = \frac{sx}{P(t)}[r(t)K],$$

$$(A.14) \quad Q_1(t) = D_{11}(t) + D_{12}(t) + C_1(t) + I(t),$$

$$(A.15) \quad Q_2(t) = D_{21}(t) + D_{22}(t) + C_2(t);$$

and by adding two more demand equations explaining C_i , capitalists' consumption demand:

$$(A.16) \quad C_1(t) = \frac{\beta_{11}}{P(t)}\{[1 - s]r(t)K - \gamma\},$$

$$(A.17) \quad C_2(t) = \beta_{12}[1 - s]r(t)K + (1 - \beta_{12})\gamma.$$

Four equations summarize the dynamic properties of the model:

$$(A.18) \quad x(t) = x(0)e^{\lambda_K t},$$

$$(A.19) \quad y(t) = y(0)e^{\lambda_L t},$$

$$(A.20) \quad \frac{dK(t)}{dt} = I(t) - \delta K(t),$$

$$(A.21) \quad \frac{dL(t)}{dt} = \{n_1 u(t) + n_2 [1 - u(t)]\} L(t).$$

The basic model can also be restated in per capita terms. Define

$$q_i(t) \equiv \frac{Q_i(t)}{y(t)L_i(t)}, \quad k(t) \equiv \frac{x(t)K(t)}{y(t)L(t)}, \quad \omega(t) \equiv \frac{w(t)}{r(t)},$$

$$z_{ij} \equiv \frac{D_{ij}(t)}{L_j(t)}, \quad \phi(t) \equiv \frac{I(t)}{K(t)}.$$

Since the production functions are linearly homogeneous,

$$(A.22) \quad q_i(t) = f_i(k_i), \quad (i=1, 2) \text{ from (A.1),}$$

and with full employment assumed,

$$(A.23) \quad k = uk_1 + (1-u)k_2 \text{ from (A.9) and (A.10).}$$

Under marginal product pricing where factor payments exhaust output and perfect factor mobility prevails,

$$(A.24) \quad \omega = \frac{f_i(k_i)}{f'_i(k_i)} - k_i, \quad (i=1, 2) \text{ from (A.5) to (A.8).}$$

Demand conditions in wage earners' households are given in per capita terms as

$$(A.25) \quad z_{1j} = \frac{\beta_{1j}}{P} [y\omega f'_2(k_2) - \gamma] \text{ from (A.2), (A.5), and (A.6),}$$

$$(A.26) \quad z_{2j} = \beta_{2j} y\omega f'_2(k_2) + (1 - \beta_{2j})\gamma \text{ from (A.3), (A.5), and (A.6),}$$

while it follows that

$$(A.27) \quad \phi = x f'_1(k_1) \text{ from (A.4) and (A.7).}$$

In per capita terms the commodity clearing equation for agricultural goods reduces to

$$(A.28) \quad y(1-u)q_2 = uz_{21} + (1-u)z_{12} \text{ from (A.3), (A.6), and (A.12).}$$

As is the case for other closed neoclassical two-sector models, the terms of trade is given by

$$(A.29) \quad P = \frac{f'_2(k_2)}{f'_1(k_1)} \text{ from (A.5) and (A.6).}$$

APPENDIX B

Table B.1 lists parameters and initial conditions utilized in Section IV. They are drawn from contemporary Asian experience, primarily the Philippines. An extensive discussion of these estimates can be found elsewhere.⁵

TABLE B.1
PARAMETER VALUES AND INITIAL CONDITIONS
UTILIZED IN SIMULATIONS

Parameters	Initial conditions	
$A_1 = 0.640$	$x(0) = y(0) = 1.000$	$u(0) = 0.300$
$A_2 = 0.350$	$K(0) = 30.174$	$v(0) = 0.429$
$\sigma_1 = 0.500$	$K_1(0) = 17.135$	$s^*(0) = 0.150$
$\sigma_2 = 1.500$	$K_2(0) = 13.039$	$\alpha(0) = 0.481$
$\lambda_K = 0.003$	$L(0) = 100.000$	$k_1(0) = 0.571$
$\lambda_L = 0.010$	$L_1(0) = 30.008$	$k_2(0) = 0.186$
$n_1 = 0.020$	$L_2(0) = 69.992$	$k(0) = 0.302$
$n_2 = 0.030$	$Q_2(0) = 94.990$	$\frac{P(0)K(0)}{GNP} = 1.854$
$\delta = 0.050$	$P(0)Q_1(0) = 71.290$	$n(0) = 0.027$
$\beta_{11} = 0.800$		
$\beta_{12} = 0.500$		
$\beta_{21} = 0.200$		
$\beta_{22} = 0.500$		
$\gamma = 0.648$		
$s = 0.312$		

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5. Kelley, Williamson, and Cheetham, *Economic Dualism in Theory and History*, *op. cit.*