

**CHOICE OF TECHNIQUE REVISITED:  
A CRITICAL REVIEW OF THE THEORETICAL UNDERPINNINGS**

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**INTRODUCTION**

Literature on economic development frequently includes statements that critically rely on a key assumption: under diverse economic environments, individual producers choose process technologies from among a set of available techniques. The choice itself is a function of a series of economic parameters such as prices, wages, and the rate of profits (or the rate of interest). As price distortions appear, because of market failure or trade union influence on the relative price of labor, the choice of technique may be affected and resources may be misallocated. Problems in areas such as growth, employment, international trade, agriculture, and industrial economics are analyzed through an approach that all too frequently relies on the crucial assumption that producers are engaged in a process of choice of technique. Recent literature, whether on sectoral or macroeconomic themes, continues to adopt this perspective. For example, many scholars believe that misallocation of resources and involuntary unemployment are caused by distortions in the relative price of labor. Thus, when making new investments producers (capitalists) select techniques of production that have a labor-saving bias in an economy with abundant labor resources.<sup>1</sup> In the field of development economics there are several classic critiques of this paradigm (Sen 1962; Bhalla 1975; Stewart 1977). The neoclassical apparatus has also attracted criticism from economists

specializing in the history of technology (Rosenberg 1976). However, their criticism was limited to the lack of realism of the production function.

A common objection is that the production function assumes the existence of a continuous succession of techniques with different combinations of production factors. Thus, it cannot deal with the existence of strong discontinuities in the production possibility frontier. These analyses, however, have essentially ignored the theoretical assumptions or foundations of the choice of technique paradigm.<sup>2</sup> Research is still frequently based on the premise that from a logical viewpoint, the neoclassical theory of choice of technique is unassailable (Amsalem 1983: 3).

The logical structure of the choice of technique paradigm hinges on three premises. First, a set of technical alternatives is readily available. Second, economic agents are familiar with each of the alternatives and can thus compare them. Third, the act of choosing one alternative does not imply any additional cost for the producer. The rules of behavior of the relevant economic agents have been clearly defined within the neoclassical framework. Maximizing behavior can be defined through conditions of first and second order (Hicks 1932; Samuelson 1947), or in the case of set production theory, where the form of the production function is not specified, through conditions imposed on the production feasibility set (convexity, closedness and boundedness) and the supply schedule (continuity) in such a way that with the aid of a well-known theorem, the existence of a maximum can be guaranteed.<sup>3</sup>

The basic idea of choice of technique is also associated with neo-Ricardian economic theory. Although the economic forces that rule the selection process are different and the theory of the individual economic agent has not been thoroughly developed, Sraffa's theory relies on essentially the same assumptions outlined above. The fact that this assumption is shared by radically different theories reveals its importance in the development of economic theory. However, very few analyses are available on the origins and main features of this fundamental perspective on technology. In so far as many of the studies in the area of development economics are policy oriented, it is necessary to examine the rational foundations of the policy recommendations emanating from them. Usually, when choice of technique is considered in policy-oriented research, no reference is made to the crucial fact that this idea is embedded in the neoclassical theory of price formation. Also ignored are the very restrictive assumptions and conditions that guarantee the formation and convergence of prices (all prices, including prices of factors of production) toward an equilibrium point and their relevance to any analysis involving the assumptions of choice of technique. Policy-oriented research frequently ignores the limitations of the theories it invokes as its rational foundation. Thus, the rational foundations of economic policies are not explicitly incorporated into more applied or policy-oriented analysis. As a result, the boundaries of validity of policy recommendations are sometimes blurred. The objective of this paper is to identify the origins, evolution and shortcomings of this assumption in order to bridge the gap between abstract theory and policy-oriented studies.

In neoclassical theory, technology is conceived as an exogenous variable and, therefore, the rate and direction of technical change remain outside the theory's explanatory power. Most of the attention is centered on the choice of technique because neoclassical tradition is based on the assumptions that the producer is familiar with the latest technological possibilities and that the movement of the relative prices of production factors provides the producer with enough information to decide which technique will maximize profits. In this way, the phenomenon of technological change is reduced to a problem of substituting production factors. When neoclassical instruments have been used to analyze economic growth, technological change has been a very important theme. Unfortunately, such analysis has remained bounded by the simplistic assumption that technological change is nothing more than a regular influx of innovations, exogenously determined and introduced at a constant rate.<sup>4</sup>

The neoclassical approach to production at the microeconomic level is based on the description of the relation between inputs and outputs. The most important are the notions of production function and the production possibility set. Both ideas are closely linked, but in the case of the production function, as Samuelson (1947) noted, an implicit maximization process (that leads the producer to discard dominated activity vectors) has already been carried out. At any rate, in both cases, available technology is considered a datum in the maximization problem. In the case of models with variable technological coefficients when changes in the relative prices of production factors

appear, the producer responds to this market signal by substituting among factors. In the model of fixed technological coefficients, the substitution is carried out through consumer markets.<sup>5</sup>

## **THE ORIGINS**

The origins of the choice of technique approach can be found in classical political economy. Adam Smith's theory of the gravitation of market prices around natural prices shows the first systematic attempt to examine the process of allocating productive resources among alternative uses (Smith 1904). A key underlying assumption is that new entrants and incumbent producers are familiar with alternative techniques of production in different branches of economic activity. However, it was Ricardo who first proposed substitution among productive resources on the basis of movements in relative prices (Ricardo 1951-52). In this way, despite the profound differences between classical and neo-classical theories of value and distribution, in both cases, technical change is absorbed into the concept of substitution among productive resources. This is remarkable considering that wages are the price of labor in the neoclassical framework, while classical political economy considers wages as a variable of income distribution.

By adding Chapter 31, "On Machinery," to the third edition of his principles, Ricardo emphasized the need to study the consequences of mechanization on the distribution of

income among different social classes. One element of Ricardo's analysis opened an interesting avenue for further theoretical development. Ricardo indicates that

With every increase of capital and population, food will generally rise on account of its being more difficult to produce. The consequence of a rise of food will be a rise of wages, and every rise of wages will have a tendency to determine the saved capital in a greater proportion than before to the employment of machinery. Machinery and labour are in constant competition, and the former can frequently not be employed until labour rises.

(Ricardo 1951-52: 387)

In Ricardo's theory of value, a change in distribution (e.g., an increase in wages) leads to a new relative price structure because the prices of the commodities produced with different proportions of capital and labor are affected in different ways. Ricardo's statement, however, really concerns the effects of changes in distribution on the choice of production techniques (that is to say, *before* the process of production is carried out). Neoclassical theory interpreted this proposition as a reference to the analysis of the substitution between capital and labor in the context of a production function, and not to the *effects* of technical change. Thus, Ricardo's analysis contributed to an analytic paradigm based on the assumption that technical change is an exogenous variable.

In the Ricardian scheme, the direction of technological change remains without explanation, although it has serious repercussions on the distribution of income among social classes. Neoclassical theory devotes a great deal of analytical effort to this problem. One of the authors who helped recover Ricardo's statements in the neoclassical context was Hayek (1942). Using the Austrian school's theory of capital in the analysis of economic cycles, Hayek demonstrated that increases in consumption reduce the rate of investment. During the rising phase of these cycles, real wages decrease and, therefore, capitalists choose production methods that reduce the period of production and are more labor intensive. In contrast, in the downward phase of the cycle, wages increase and capitalists choose capital-intensive techniques that lengthen the period of production. This phenomenon is due to what Hayek labeled the "Ricardo Effect" (i.e., the replacement of work by machinery when wages increase and the reverse when the interest rate rises). In this analysis, the techniques associated with an increase or a reduction of the average length of the period of production are considered to be readily available during the entire process.<sup>6</sup>

The fact that these theories consider technology an exogenous variable explains why they do not regard technological change as an important theme. In contrast, the theme of "technology choice" acquires great importance. Working under the assumptions of substitution and rational behavior, neoclassical tradition concludes that when a new investment is made, the technique chosen from a catalogue of available technology is the one whose marginal rate of substitution among factors (i.e., the ratio between the

corresponding marginal products) is equal to the slope of the factor price curve.

However, this analysis is embedded in the neo-classical theory of price formation. The assumptions required to guarantee a coherent process of *price formation* and *convergence* are seldom mentioned.

## **CHOICE OF TECHNIQUE AND INDUCED INNOVATIONS**

Many authors have pointed out that factor substitution does not correspond to a process of technical change; the latter can only be understood in terms of a displacement of the production function itself (or modifications in the configuration of the production possibility set). In fact, even the heuristic value of the idea of a production function for the study of technical change has been the object of serious criticism because it implies that the transition from one technological alternative to another is continuous and without sudden jumps. In this way, any possibility of analyzing technological discontinuity is eliminated. This idea also implies that an economy has information about combinations of production factors that could be quite different from the factor endowment actually available within that particular economy. This means that the economy has information on technical combinations far away from the interval of the production function relevant to its real factor endowment (Rosenberg 1976). As a result, the production function can provide no information about the origins of a specific range of technical options or about the nature of the economic forces that determine its existence.<sup>7</sup>

According to this description of available technological alternatives, technological change in the strictest sense can only be understood through a displacement of the production function. Nevertheless, the problem of this displacement is very complex and presents serious difficulties to the neoclassical approach. The theme of “induced technological change” is based on the question of whether the structure of relative prices provokes or induces technological changes that make it possible to cut back on more costly investment capital. After attempting an initial classification of innovations as a function of factor participation in distribution, Hicks theorized that technological change is induced by modifications in the relative prices of production factors.

According to this theory, inventions fall into two large classes: “autonomous” and “induced” (by movements in factor prices). As Hicks stated: “A change in the relative prices of production factors is, in itself, an incentive to invention, and invention of a certain type - aimed at cutting back on the factor that has become more expensive” (Hicks 1932: 124).

This type of statement encouraged research on the history of technology to examine the conclusions of Hicks’ model. Hicks himself opened this road with a brief review of the previous 200 years of European economic history, concluding that labor-saving technological changes have had more impact than capital-saving changes. Other historians such as Habakkuk (1962) and David (1974) have followed this line of

investigation, but their conclusions show that relative prices are neither the only nor the most effective parameter for stimulating innovations.<sup>8</sup>

On the other hand, the idea of innovations “induced” by changes in relative factor prices implies that the production of technological information can be represented by a production function; one of the arguments of this function would be the relative prices of production factors. In this context, it is important to remember that Salter (1960) and others criticize Hicks’ statements on the grounds that the producer’s objective is to minimize total cost and not simply reduce a specific cost: any increase in the wage bill can be countered with technologies that are less labor or capital intensive.<sup>9</sup> This criticism once again emphasizes factor substitution at the expense of technological change, but it is not the only criticism directed at models of “induced” technological change. If the lessons learned from empirical research on inventive activity are also considered, it is impossible or very difficult to predict the results of research and development (R&D) activities. Under these conditions, there are absolutely no grounds for claiming that the outcome will be induced by changes in relative factor prices.<sup>10</sup> Kennedy (1964) and Weizsacker (1966) concentrated on “applications” of available knowledge instead of posing the problem of new inventions per se. According to this approach, managers try to maximize “technological progress” (corresponding to a function of maximizing reductions in unit costs) along a “limit of invention possibilities.” Each point on this curve represents the inverse relation between increments of capital and labor.<sup>11</sup> But the position of the curve is not determined by the

relative prices of production factors and, consequently, factor substitution is once again the dominant theme. Thus, the Kennedy-Weizsacker approach returned to the view that technology is determined exogenously and technological change does not depend on changes in relative prices. The theory of induced bias in innovations was abandoned, marking the return to the choice of technique paradigm. In fact, we are left with a series of definitions, such as neutrality in Hicks' or Harrod's sense, that can only be *ex-post* explanations in a framework of comparative statics.

Faced with the problem of technological change, neoclassical theory finds itself in serious trouble. If technology is considered a datum for the producer, then the producer chooses from among different alternatives as a function of relative factor prices. In this case, technological change is reduced to a simple problem of factor substitution, but the bias in this substitution cannot be defined because in equilibrium the producer is not interested in any particular type of cost reduction. However, if technology is considered an exogenously determined set of possibilities, it is impossible to develop a theory about technological change. At the beginning of the 1960s, the weaknesses in this analysis of technological change were recognized, but it was still regarded (Blaug 1963) as the most effective frame of reference for organizing our knowledge about the subject. The theoretical debate that followed, however, revealed that such enthusiasm was unfounded.

## **CONTEMPORARY CLASSICAL POLITICAL ECONOMY AND CHOICE OF TECHNIQUE**

The work of Garegnani (1960) and Sraffa (1960) initiated a period of intense criticism of neoclassical theory, directed mainly at its concepts of capital and of marginal productivity as the determining element in distribution. Garegnani concentrated his criticism on Walras' (1952) capitalization equations but Morishima (1964) demonstrated that, by using a more general definition based on inequalities, the existence of equilibrium in an economy producing capital goods could be guaranteed.<sup>12</sup> Garegnani's critique of Walras played an important role in the theoretical development of the 1970s but seems to have been based on a confusion between stability and equilibrium.

Sraffa's (1960) criticism of the theory of marginal productivity gave rise to a theoretical debate with vast implications for marginalist theory. As far as choice of technique is concerned, Sraffa's work challenged the idea that there is an inverse and monotonic relation between the total amount of capital per employed worker and the level of the rate of profit. As a result, the neoclassical theory of marginal productivity was put on the defensive (for a detailed account of the debate, see Harcourt 1972). Today, the intensity of the debate has diminished, the neoclassical theory of capital has continued to be developed and the problems presented by the concepts of technology and technical choice still occupy an important place (e.g., Brown et al 1976).

Sraffa's (1960) work powerfully criticized the theory of marginal productivity, the concept of production factors and an aggregate production function and, consequently, the idea of factor substitution.<sup>13</sup> This critique is synthesized in the phenomenon of "switching of techniques" (i.e., the fact that the same production technique that was considered the most efficient at a certain level of profits may be discarded when profits rise and, later, chosen again as the most efficient at even higher levels of profit).<sup>14</sup> This phenomenon, so surprising for orthodox neoclassical theory, is a normal element of the world of production by means of produced inputs and leads to results difficult to assimilate into neoclassical theory.

In spite of its profound differences with neoclassical theory, Sraffa's analysis has been considered a possible foundation for the analysis of choice of technique (Steedman 1977). Even in this limited sense, however, various difficulties must be overcome. For example, if technology is chosen for the production of basic commodities (i.e., commodities entering directly or indirectly into the production of all other commodities), we are faced with the problem of comparing two different techniques (Sraffa 1960). Each economic system has a unique, standard (composite) commodity guaranteeing exact value measurements in a system of production by means of produced inputs.

In comparing two economic systems, they can be conceived as matrices of technological coefficients that, at the points of intersection of their technological frontiers of distribution possibilities, differ only in a column and line vector.

Nevertheless, as Bharadwaj (1970) notes

...the assumption [required for the analysis of reswitching of techniques] that the two productive systems are made up of the same number and type of basic commodities, but have different methods of production is extremely restrictive because it is difficult to find two different methods that use identical inputs and tools.

(Bharadwaj 1970: 415)

In addition, it is necessary to explain how economic forces act on these individual agents. In the words of Steedman (1977)

Faced with one or more available methods for the production of each commodity and with a given real wage bundle which must be paid to each worker, capitalists in each industry will seek to adopt that production method which minimizes costs and maximizes the rate of profit. The forces of competition will lead to that selection of production method, industry by industry, which generates the highest possible uniform rate of profit throughout the economy.

(Steedman 1977: 64)

Thus, without an adequate theory of intercapitalist competition (which, in turn, requires a theory of market prices), the Sraffa-based analysis of choice of technique can advance very little. Steedman (1984) shows the difficulty of developing a theory of market prices and intercapitalist competition in a Sraffian economy, because it is impossible to establish a positive correlation between changes in market prices and the (market) profit rate in each branch. Since the convergence of market prices to a vector of prices of production (with a uniform rate of profit) cannot be established, the model cannot show that capitalists choose the “most efficient” technique (market prices higher than production prices may be associated with sectoral profit rates lower than the natural rate of profit).

Neo-Ricardian theory has not been able to offer an explanation of the process of technical change. In fact, in more developed models, the phenomenon of substitution depends entirely on an autonomous normal pattern of technical progress (Pasinetti 1983). In this context, it seems that the main issue is related to the fundamental problem of how economic theory can integrate a concept of technology into its discourse.

## **NEO-WALRASIAN GENERAL EQUILIBRIUM MODELS**

During the 1970s, it was thought that Sraffa’s critique destroyed the foundations for a possible theory of factor substitution as a function of relative price movements because there was no monotonic relation between interest rates and the capital-labor (or capital-

product) ratio.<sup>15</sup> Although this critique does apply to marginalist theory, Hahn (1981) correctly states that contemporary general equilibrium theory is unaffected. Nuti (1976), another of the outstanding participants in the controversy over the concept of capital, states the following:

Within a multi-commodity multi-period system of general equilibrium, the vexed question of the measurement of capital presents no difficulty. The value of a capital asset is the present value of its net output over time, i.e., the value of the discounted flow of the outlays and receipts associated with it. The value of the capital stock of an economy is the present value of its reproducible physical assets (non-reproducible assets are classified as “land”). The accusation that an implicit assumption of malleable capital exists in the multi-commodity multi-period model (Garegnani 1960) may hold for Walras’ treatment (1900, lesson 41) but not for recent formulations (Debreu 1959) where the allocation of all inputs, the level of outputs and the prices of inputs and outputs are all determined *simultaneously*, given productive transformation possibilities, individual preferences, competitive exchange, and wealth and utility maximization. One thing that cannot be done within this model is to use the aggregation of capital goods at the given equilibrium prices to construct an aggregate production function summarizing alternative states of resource allocation.

(Nuti 1976: 75)

In other words, in Arrow-Debreu models, there is no room for a concept of capital or uniform profit rates, or for the aggregate measurement of capital. Furthermore, there is no simple relationship between interest (or wage) rates and what could be considered technological characteristics of the system (such as the relative scarcity or intensity of capital).

In contemporary general equilibrium models, producers choose the activity vector that maximizes their income, taking into account the prices of investment capital and its products. In this way, technology is also an exogenously determined component of the model and the producer, acting as a price taker, only has to choose from among different alternatives. Of course, the hypothesis of perfect substitution among inputs is a basic part of this analysis and, as such, contradicts one of technology's most important characteristics.

Neo-Walrasian general equilibrium models have other serious problems.<sup>16</sup> They have not been able to incorporate a convincing analysis of the dynamic processes of price formation and stability. In this sense, the stability analysis by Arrow and Hurwicz (1958) and Arrow et al (1959) still represents the state of the art. There is a consensus that their results are rather modest because, among other things, a crucial assumption of gross substitutability of all goods is required. Thus, economic systems for which these stability theorems apply can only have goods for which the cross price elasticities have a positive sign. This is, of course, extremely restrictive. A similar assumption must be

introduced to guarantee the uniqueness of equilibrium. This is of great importance in policy-oriented research. Policy recommendations are almost always based on comparative statics, where the assumption of uniqueness of equilibrium is crucial.<sup>17</sup>

In relation to the theory of price formation processes (including the prices of factors of production), general equilibrium models face an endemic problem described by Arrow and Hahn (1971): if all firms are competitive and thus have price-taking behavior, who changes prices during the adjustment process? This unsolved problem is critical and has been the source of considerable embarrassment for neoclassical economics. Attempts to solve this problem are based on a procedure first introduced by Walras in his theory of production: a market auctioneer acts as the central authority charged with announcing price vectors that are the parameters in the agents' maximizing calculations. Once individual supply and demand plans have been determined, the auctioneer centralizes this information, calculates excess demands and adjusts prices of individual markets that are not in equilibrium. This central figure is needed in all versions of the neoclassical price formation process.<sup>18</sup>

The presence of a *central authority* performing such an important task as adjusting prices, however, contradicts the essential features of the definition of a decentralized market economy. The issue is relevant to the choice of technique because factor prices are formed through the same processes. This means that neoclassical theory does not have a *particular* explanation of the price formation mechanism for productive factors

such as capital and labor. Thus, for example, agents offer to sell and purchase labor at the going prices and announce these intentions to the auctioneer who, in turn, recalculates excess demand and adjusts prices accordingly. Thus, in the field of price formation mechanisms, general equilibrium theory is plagued by assumptions that are both restrictive and necessary.<sup>19</sup>

The difficulties facing the idea that productive agents are involved in a process of choice of technique are not only present in price formation theory. The theorems that prove the existence of a competitive general equilibrium in Arrow-Debreu models require conditions and assumptions that have serious implications for the theory of choice of technique in a microeconomic context. The demonstration is carried out by applying fixed-point theorems to a complex mapping that is interpreted as the excess demand correspondence (e.g., see Debreu 1959; Nikaido 1968; Arrow and Hahn 1971). Every individual producer is endowed with a production feasibility set, which is composed of possible production vectors. The production sets are assumed to be convex and closed, but not bounded. This entails a serious difficulty: if possibility sets are not bounded, the production vector associated with a maximum profit may not exist. When facing price vectors in a competitive economy, individual agents will be unable to behave as theory predicts; the productive agents are incapable of choosing among alternative techniques to maximize profits. This difficulty is rarely recognized in the literature involving applied research; in fact, the conclusions of applied research and policy recommendations frequently imply an assumption that agents select production

vectors from their production possibility sets without any problem. However, every author that has made a meaningful contribution to proving the existence of competitive equilibrium has had to introduce the hypothesis that individual production possibility sets are bounded because they are intersected by the *aggregate* feasibility set. Because the aggregate feasibility set is bounded by limited (unproduced) resources, it is thought that the intersection is enough to justify boundedness as a property of the individual possibility sets. The nature of this problem has been analyzed in detail by Nadal and Salas (1987). The difficulty can be restated in the following terms. Individual agents have production possibility sets where each element is a production vector. The sets are closed and convex, two more or less harmless topological properties; but boundedness cannot be assumed because the agents are defined as maximizing agents. If the set is not bounded, the image set of the supply function, which is a standard maximizing function, may be empty (i.e., there is no production vector to maximize profits). Because it is not possible to assume that production sets (or consumption sets) are bounded, the only way to introduce boundedness is through the overall restriction of the economy: resources are limited and the economy cannot produce infinite quantities of commodities. The behavior of individual agents is restricted to the intersections between individual possibility sets and the aggregate feasibility set. However, the theoretical implication of this assumption is that individual agents have information on the technology and resource endowment of the *entire economy*. This contradicts the objective of a theory of the allocative efficiency of the market mechanism, which is to demonstrate that a

competitive equilibrium exists for an economy made up of individual agents, possessing nothing more than private information on a decentralized basis.

## **IMPLICATIONS FOR APPLIED RESEARCH AND POLICY**

A clear implication of the previous analysis is that the choice of technique paradigm should be abandoned. It not only lacks realism, as most of its critics have observed, but also the theoretical construct in which it is embedded (e.g., the price formation mechanism) is not as solid as some researchers pretend. Choice of technique is a paradigm originating in a discussion on income distribution and price formation (e.g., the work of Ricardo, Hayek and Hicks). It does not emanate from a theory directly concerned with the issues of technical change, growth, or technological development. Applied research on the problem of technological change has gained very little from continued use of this frame of analysis. It should be stressed that individual firms' technological behavior must necessarily be considered as part of the pattern in which industrial branches evolve through time. The choice of technique frame of analysis does not provide a good vantage point. The internal factors of each branch must be analyzed (e.g., forms of competition, technical features of product and process technology, dynamics of market shares, and growth of individual firms). The modern theory of industrial organization shows that an individual firm's behavior does not make sense outside of the environment in which it takes place.

The choice of technique paradigm should be definitely abandoned, not substituted by more sophisticated versions of the same principle. In particular, a revival of the idea in the guise of a generalized, multifactor model should be avoided. For example, Amsalem (1983) pretends that the lack of realism of the two-factor model can be surpassed by introducing production input structures. Because we are now working with a multifactor model in which all inputs are considered (e.g., capital goods, labor skills, raw materials, and spare parts) at a given scale of production technology, selection becomes a matter of matching technology's input structure with a country's factor price structure to minimize production cost. It is then possible to evaluate the impact of factor price distortions on technology choice, and the analysis is back on the track of the traditional maximization problem. It is not possible to generalize with meaningful results a theory which is devoid of meaning in the canonical or elementary version. The problems of the theory of price formation that have been identified also apply in the case of multifactor models and input structures.

Even the most advanced use of this tool (i.e., in the theory of contestable markets) cannot be considered a theory of technical change. The most developed model (Baumol et al. 1982) can handle multiproduct cost functions, scope economies, and other relevant elements for a sound theory of production and competition in modern industry. The introduction of new capital goods is possible because pricing and depreciation practices can be readily incorporated into the model. The model handles cases in which exogenously determined new techniques are given (the prices of capital goods are

considered to be falling when the new technique is available and infinite before this happens). It does not, however, approach the question of the economic forces behind the generation of these new techniques. In other words, the model allows for introducing new pricing and depreciation configurations when more efficient capital goods are introduced (considered as input-saving innovations). Unsustainability may occur because of a series of technology-related factors (scale economies in sunk costs, learning by doing, etc.). Much work is still needed in order to use this theory to explain the economic forces behind the generation of new technologies.

The most important policy implication is that there is no rational foundation for the belief that firms choose techniques of different factor intensities as a function of relative factor prices. There may be elements in ill-conducted empirical research that suggest this is the case; but the industrial environment and policy making are much more complex. Even if minimum wage legislation, social security charges and legislation on job security were eliminated, the forces of intercapitalist competition (both national and international), technological features of production processes, as well as expectations and scales of production, would likely all act on the decision-making process. In fact, in a period of a sharp decline in real wages in Mexico between 1980 and 1989, with a centralized and docile trade union movement, it is doubtful that firms have selected more labor-intensive production techniques better in tune with the national factor endowment.

The basic elements of the choice of technique paradigm are still advanced as a relevant frame of analysis of technology in developing countries. They crop up repeatedly in the research of influential institutions in the area of policy making. For example, in research sponsored by the World Bank, the paradigm is frequently used (Dahlman et al. 1987; Balassa 1988) to support the idea that social security and minimum wage measures are the causes of misallocation of resources and inefficiencies. The theory of price formation on which this idea rests is not a solid foundation. Empirical research, whether academic or policy oriented, cannot continue to ignore this basic fact.

Much applied research on issues related to technology policy (transfer, assimilation and adaptation of technology) was carried out in Latin America during the last two decades. The issues were largely limited to the firm (or even shop) level, but experience showed that these issues had to be considered within a context in which industrial organization, expectations (both economic and technological), financial variables, macroeconomic policies, and trends in international trade and competitiveness were taken into account. Similarly, policies on technology-related issues in Latin America in the 1960s and 1970s practically ignored monetary and financial variables.<sup>20</sup> A strong engineering bias covered the conceptualization of firms' technological behavior (generation, acquisition, and adaptation of techniques).

The economic crisis of the 1980s revealed how shortsighted this approach had been. But, in today's world of drastic adjustment programs and anti-inflationary packages

(including trade and financial liberalization), technology policy is ignored altogether or reduced to a series of recipes regarding the performance of the market mechanism to guarantee efficient choice of techniques. This is another extreme view of economic policy in which efficient decisions on real world variables are left to the invisible hand. This naive view of economic dynamics must give way to a sound perspective in which the technology and other real variables are given proper attention.

Studying the origin of the choice of technique paradigm reveals one important lesson: there should be a minimum correspondence or affinity principle between the type of questions asked and the analytical apparatus used. For example, policy-oriented research on issues that are only intelligible at the level of an industrial branch or a complex of industrial branches should not be approached on the basis of analytical tools that are only relevant in the framework of individual firms. The answer to problems involving financial variables cannot be unraveled with the aid of analytical tools that cannot take financial or monetary dimensions into account. It is interesting to observe that much of the empirical research on technology transfer, assimilation and adaptation in Latin America ignored the role of financial variables. With this omission, it was impossible to integrate macroeconomic policies and the dynamics of profitability into this analysis.

In the next few years, the discipline will witness a revolution that will yield exciting analytical tools for more relevant research for science and technology policy making in

developing countries. There will be path-breaking work in the areas of industrial organization, resource management, mathematical applications for complex and dynamic systems, and self-organization models. In particular, results will come from new trends in evolutionary economics and from the analytical work of the new institutional economics. A new way of establishing linkages between the lessons of economic history, the history of technology and economic theory will also offer new vantage points that may reorient applied research. Empirical and policy-oriented research should be on the alert as to the future orientation of these developments.

## CONCLUDING REMARKS

All theoretical statements may have universal validity, but only under restrictive conditions. Outside these conditions, theoretical utterances are unintelligible. If these conditions are ignored, there is a risk of serious confusion: the validity of theoretical statements is extrapolated and extended beyond their rational scope. When pure theory is invoked as a rational foundation of policy recommendations, it is critically important that the validity of theoretical statements be considered. As the discipline stands today, the gap separating pure theory from applied research is already enormous. Researchers must not compound this problem by the erroneous practice of invoking the results of pure theory without explicitly recognizing the boundaries of their validity.<sup>21</sup>

Although applied research elaborates on empirical results, it also frequently invokes pure theory. Thus, conclusions supposed to be firmly established constructions of pure theory are presented as a supplement to empirical data. Through this procedure, empirical data are frequently endowed with an apparently more coherent structure, their robustness is overstated. It is the central argument of this paper that policy-oriented research should explicitly consider the extremely restrictive conditions of the theoretical statements it invokes. This should be a regular habit of relevant applied research, particularly in relation to the dynamics of price-formation mechanisms and the existence of general equilibrium. Because the choice of technique assumption rests on the theory of price formation, any reference to the theoretical aspects of this notion

should bring to light the restrictive conditions under which statements on the existence, uniqueness, and stability of equilibrium make sense. This is crucially important in the realm of applied research. If policy recommendations extend beyond the limits of validity of these rational foundations, they may have disastrous consequences.

## **ENDNOTES**

<sup>1</sup> According to this view, if distortions of relative prices of production factors last long enough, the direction of inventive activity will also be affected as biases appear in factor-saving orientations of new process technologies.

<sup>2</sup> Ironically, much of the discussion on appropriate technology of the last decade (with all its critical flavor of the neoclassical maximization approach) rests on the same logical assumptions. Analyses that became classics of the economic development literature also relied heavily on the validity of the assumptions of choice of technique.

<sup>3</sup> The theorem (Weierstrass) states that if  $f$  is a function from  $S$  to  $R$ ,  $f$  is continuous on  $S$  and if  $S$  is compact and nonempty, then  $f(S)$  has a maximum and a minimum. The theorem is widely applied in all neo-Walrasian models for supply and demand schedules.

<sup>4</sup> See, for example, Uzawa (1960-61) and Solow (1961-62) and, a few years later, the concept of “vintage models,” which incorporates successive generations of capital goods. For a classic review of works on growth and the introduction of suppositions about “technological progress,” see Hahn and Matthews (1964).

<sup>5</sup> It is interesting to note that there is a strong analogy between the theories of the producer and the consumer. Sraffa (1975) was the first to observe this analogy in the context of his criticism of Marshall’s theory of variable returns. Carrying Sraffa’s observation further, as the producer, the consumer in neoclassical theory also faces the problem of choosing a vector of inputs (set of consumer goods) as a function of both relative prices and indifference curves, which represent the particular “technology” to produce a particular good called “satisfaction.” In this way, consumption and production theories share a similar structure in which the position of production isoquants and indifference curves is considered an exogenous datum. The choice of technique paradigm indeed covers under its logical mantle the problem of the maximizing consumer.

<sup>6</sup> Hayek’s analysis was subjected to strong criticism, notably by Kaldor (1960), who sarcastically renamed his theorem the “Concertina Effect.” In Kaldor’s criticism the “Concertina Effect” is considered to be nonexistent or insignificant and the “Ricardo Effect” is attributed to Wicksell. Kaldor makes it clear that for Hayek, the element that determines the greater or lesser use of machinery (or of labor) is the rate of profit per capital unit. For this reason, what Hayek calls the “Ricardo Effect” implies that, when labor earns more profits than capital, companies then substitute machinery for workers independently of changes in the relative prices of labor and machinery. But, for Ricardo, this substitution depends exclusively on this change in relative prices.

<sup>7</sup> Some neoclassical authors have attempted to solve this problem by considering that the production function includes all *possible* designs that can be attained with the existing stock of technical information. Examples of the above are provided by Salter (1960) and, in a different context, Hayami and Ruttan (1971) through their concept of “metaproduction function.” Rosenberg (1976) criticized these attempts on the grounds that statements regarding long-term movements along the

production function toward points that are still unknown are extremely ambiguous, at least from the economic point of view.

<sup>8</sup> David (1974) recapitulates the discussion about the definition of the so-called “technological trajectories.” In effect, David’s analysis leads to the idea that, for strictly technological reasons, more of the new capital-intensive production technologies introduced during the second half of the 19th century were “neutral” (in Hicks’ sense, that is to say, the marginal products of capital and labor factors were equally affected) than less capital-intensive technologies introduced during the same period. Surprisingly, these conclusions are frequently cited to support those theorists who regard innovation bias as induced by the relative prices of factors of production. In fact, what David’s study really shows is that, in some cases, the flexibility of engineering parameters does not depend on relative factor prices.

<sup>9</sup> Fellner’s (1962) argument can be summarized as follows: in the case where there is no quantitative rationing of production factors and assuming that there is perfect competition, the theory is incapable of showing that the market offers incentives for finding ways to cut back on the use of a *particular* factor.

<sup>10</sup> For Nelson and Winter (1982) movements through unexplored regions of a production function should be rejected as a theoretical concept. Furthermore, the idea that innovations are induced in an attempt to rectify the production function for remote combinations of production capital is unconvincing: it supposes that “inventing” or R&D are activities whose results can be predicted in considerable detail. In fact, there is absolutely no difference between the theory that physical investment in one type of capital (plant and equipment) causes movements through the production function and the theory that R&D investments in another type of capital (knowledge) pushes the production function “toward the outside.”

<sup>11</sup> In other words, Kennedy’s (1964) central idea is that a better growth rate of the capital factor can only be obtained by decreasing the growth rate of the labor factor.

<sup>12</sup> Nevertheless, Morishima did not provide a satisfactory analysis of the stability conditions of this equilibrium.

<sup>13</sup> The possibility of introducing the analysis of technological choice into a system of prices of production requires a series of suppositions about the commodities that are produced in *two* systems. In trying to simplify the assumptions, Bharadwaj (1970) showed that the number of points with reswitching of technology between two systems is determined by the number of commodities that enter directly or indirectly into the production of a “reference” commodity produced in both systems. The phenomenon of reswitching techniques is not necessary to invalidate the idea of the existence of an inverse, monotonical relationship between interest rates and the arrangement of production technologies according to a criterion of “capital intensity.”

<sup>14</sup> Each level of distribution can be represented by a point on the technological frontier of income distribution possibilities. A price vector is associated with each point. The frontier is formed by the dominating segments of the income distribution possibility curves associated with each one of the techniques being compared. In fact we can show on the technological frontier that at the same level of profit, the relative price vector of the “dominant” technique is inferior to that of the “dominated” technique. At the intersection points the price vectors are equal.

<sup>15</sup> On the basis of Sraffa’s work even authors such as Samuelson (1966) conclude that there is no clearly defined relationship between the relative prices of factors and the intensity with which these factors are used.

<sup>16</sup> Other problems of this theory are related to the mathematical formalization used. For example, neo-Walrasian models define a commodity space that is an isomorphism of the space  $R^n$  (i.e., copy of the space of real numbers). In this way, the dimensional problems that arise from the heterogeneity of capital goods (and of all commodities) are suppressed. Furthermore, use of the space of real numbers makes it possible to introduce perfect divisibility of all goods. Another important problem is related to the assumption of convexity required for production possibility sets. This assumption is required to prove the existence of equilibrium but rules out the possibility of increasing returns to scale.

<sup>17</sup> Uniqueness of equilibrium is an implicit assumption in policy recommendations involving comparative statics. Because the proof of uniqueness requires such a restrictive condition as gross substitutability, this fact should be explicitly recognized.

<sup>18</sup> In the so-called *tâtonnement* processes, no transactions are allowed before general equilibrium is reached. So-called *non-tâtonnement* models, where exchanges out of equilibrium are allowed, are pure exchange models and cannot handle production. The distinction between these two processes was first made by Negishi (1962). For a review of the history of stability analysis and the role of this assumption, see Fisher (1983).

<sup>19</sup> In addition, these models face severe difficulties in the integration of monetary variables into their framework. In particular, as Hahn (1969) has shown, in the Arrow-Debreu general equilibrium model, solutions in which the price of money is null represent equilibrium price vectors. Thus, general equilibrium models always allow for a nonmonetary solution. For this reason, the theory of general equilibrium seems condemned to remain in the limbo of nonmonetary analysis.

<sup>20</sup> It is interesting that the first controls of licensing contracts in the region were established in Colombia because of worries over the negative effects of royalty and overpricing practices on the balance of payments. The Royalties Committee operated in the central bank. However, this concern with macroeconomic variables was not accompanied by the introduction of financial variables in the analysis of individual firms’ technological behavior.

<sup>21</sup> There is a strong contrast between the rather modest statements found in theoretical literature on the scope and validity of results and the degree of arrogance deployed in more applied research literature involving policy recommendations. This contrast will probably diminish as the scope of validity of pure theory is explicitly recognized.