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A SYSTEMS CONCEPT APPROACH TO THE EXPLANATION AND PREDICTION OF TECHNOLOGICAL CHANGE: AN ECONOMETRIC STUDY

The University of Nebraska - Lincoln PH.D. 1985

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by

George W. Mechling, Jr.

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A Systems Concept Approach to the Explanation and Prediction of Technological Change: An Econometric Study

BY

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George W. Mechling, Jr., Ph.D.

University of Nebraska, 1985

Advisor: F. Gregory Hayden

The variance in functional measures of technological artifacts different from each other in kind is analyzed with an autoregressive stochastic model. An important feature of this model is that in the process of estimating its parameters it takes into account the moving-average structure of the error term its form implies. This capability is significant with respect to the analyses conducted in this investigation. Its exploitation generates results dramatically different from those generated by similar but less rigorous analyses.

The autoregressive form of this model derives from stated premises concerning the nature of technological change. Formalized, these premises permit two hypotheses to be tested, learning by doing/using and scale of utilization. Aircraft of the domestic trunk airlines and rail locomotives of the Class I Railroads of the United States railroad system embody their respective technologies and are the artifacts of this investigation. The variance in the functional measure of the aircraft is analyzed with the above two hypotheses from 1947 or 1952 to 1976. The results indicate that both hypotheses explain the variation over the estimation period of 1947 or 1952 to 1965 well. Futhermore, the estimates exhibit generality inasmuch as they prove stable outside the sample set in the prediction period, 1966-1976. The variance in the

functional measure of rail locomotives is also analyzed for the period 1972 to 1984. Only the learning hypothesis is tested and no attempt is made to determine whether or not the parameters estimated are stable outside their sample set. The learning hypothesis explains the variance in the functional measure of rail locomotive technology well also. This is sufficient to permit a comparison of estimates to be engineered. The results of such comparisons determine that different technologies vary with respect to how responsive they are in terms of their artifacts' functional measures to variation in their respective arguments. This is suggestive for policy on productivity in which technology is generally acknowledged to prominently figure. This research implication, the link betwixt economic and functional measures, an agenda for refining and extending the application of the research program partially introduced with the analysis conducted etc. are also subjects of interest to which this investigation attends.

ACKNOWLEDGEMENTS

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Finally, a very special note of appreciation is due my family for their support and encouragement during my graduate studies.

This Effort is Dedicated
to the Memory of
my Father

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CHAPTER I

INTRODUCTION

This investigation concerns itself with the phenomenon of technological change or innovation. The point of view from which this investigation is conducted is more that of the economist than the engineer although for reasons to be subsequently advanced this bias is not as extreme as is often the case with most economists. The importance of technology and the change or innovations through which it evolves cannot be overstated, it is generally thought. Especially this is so with respect to economics. A perusal of the stacks of a university library can quickly demonstrate that. A substantial body of literature is to be found that is devoted to the relationship betwixt the activity of an economy and the technology it employs. This devotion is found certainly in literature for which some emphasis on that relationship is the prime topic. It is found no less with varying degrees of emphasis elsewhere where it is not primary--even unto principles texts. The role the factor of technology and its evolvement play with an economy is understood in a number of different ways. Despite these differences in understanding, it is generally agreed, however, that technology is important to an economy in an essential way and technology's change or innovation is also important in an essential way. These differences of understanding do, however, suggest that if the relationship betwixt an economy and its technology is something that is at all comprehensible, understanding stands some chance of being confused. This confusion has been brought to the discipline's own members' attention on numerous occasions.[1] Whilst the criticisms have

generally been incisive and sometimes embarrasingly so, they have not been sufficient to spur conceptual developments within the discipline toward a more coherent integrated understanding as to what it is about technology that makes it so important. An exposition on the state of the discipline with respect to its treatment of technology will be presented in Chapter Two of this investigation: The Literature Review.

This investigation's treatment will be on a tack different from any of those discussed in Chapter Two. Pursuing this tack is prompted on several counts. A rather devastating conclusion that can be drawn from the literature review is that, for the most part, the discipline cannot identify a measure of technical change, let alone explain its relationship to the economy which its study purports to do. Such a conclusion discourages serious commitment to any one of those views reviewed except in the most partial and qualified way.

There are, however, alternative ways of addressing the phenomenon of technology, its change or innovation, and its relationship with its economy. These alternatives do not belong to what has become the conventional treatments of this phenomenon reviewed in Chapter Two. They possess some degree of freshness and certainly novelty and they are in many ways consistent with the ideological biases of this writer. The exposition of a crude synthesis of such alternatives is presented in Chapter Three. This chapter is in three parts and provides the conceptual basis for this investigation's undertaking. Inasmuch as measures of technical change or innovation are generally lacking prior to any attempts at explaining its economic relationships in the more conventional studies, this investigation takes as its point of departure

the work of Devendra Sahal in which unambiguous measures of technical change and their behavioral explanations are pursued. A rather extensive discussion of his work is to be found in the first section of Chapter Three. This section is followed by brief expositions of two representative sources of thought which independently tend to corroborate Sahal's assumptions and premises and incidentally are consistent with this writer's biases. The conclusion of Chapter Three emphasizes two important points. First, the advantages Sahal's work may lend those two sources of thought (Institutional Theory and philosophy of systems) toward which this writer is biased is well published. Second, justifications are advanced as to why given conclusions that can be made about the results of Sahal's work, further exploitation of his research program should be undertaken. It is in the context of these justifications that the primary thesis of this investigation is advanced. Central to Sahal's work are two hypotheses of learning by doing/using and scale of utilization and how technological change or innovation defined in terms of changes in certain performance measures of some given technology's artifacts is explained by them. Given the interest in Sahal's work demonstrated by Chapter Three and the shabby method and procedure which, it will be seen, characterizes his investigation, this investigation seeks to conclusively reject his hypothesis at a reasonable level of significance. All else developed in this investigation hangs on this thesis.

Chapter Four provides a rather lengthy discussion of this investigation's research design. This is necessary because peculiar problems in rigorously implementing Sahal's research program arise which

require exacting treatment.

Chapter Five consists of a methodological exposition and report of this investigation's results. Both appear in the same chapter because the choice of methodology is dramatically significant to the kind of results this investigation generates in comparison to Sahal's. The methodology used for this purpose is stochastic, employing auto-regressive models in which the presence of a moving average disturbance term is accounted for in the estimation process. The significance generally and importance specifically to this investigation of this methodology is stressed.

Chapter Six is the final chapter. It consists of varied conclusions that can be drawn from this investigation. It also includes a section of caveats lest perspective is lost as to what the procedure, methods, and assumptions of this investigation have managed to accomplish. The last section contains a brief taxonomy of directions in which this investigation's research program may be further extended in the future.

A concern which underlies the course this investigation takes is the desire and intent to generate the kind of results which at least have a promise of practicality. Given that a phenomenon regarded as essential to an economy as technology and its innovation is generally regarded to be, the vitality of the economy is linked to something intimately practical. Yet, there is little that has apparently been practically said about it. The desire and intent of this investigation is to contribute to some practical movement as to where intellectual effort is expended in the attempt to comprehend the relationship which

obtains betwixt technology and its change and its economy.

Perceiving this relationship as something of intimate practicality implies that such a phenomenon can be the subject of policy which is informed by the understanding of it. There will be no policy analysis in this investigation. Very little, in fact, will be said of policy in this investigation except in the final chapter when implications of the results of the research are being identified. Inasmuch as policy implications are deemed an important topic, given the practical desire for undertaking an investigation of this sort, such implications of the results generated are hardly surprising. Thus, some comment is in order identifying to some necessary degree what the policy is about which implications can be drawn from the results generated.

A concern of recent has been the differential productivity of the United States economy. Productivity growth rates vary from sector to sector and industry to industry. This has caused some alarm because there is no á priori reason as to why this could not be cause for setting into motion disruptive forces that can reverberate through an economic system. Opposing views are held as to whether the practical adjustments required to reduce such a risk lead to balanced growth or some efficacious pattern of synchronized and integrated differential productivity growth rates. The latter view is much more sophisticated and complex than a view of balanced growth. Be that as it may, the cause of differential productivity has for the most part been a puzzle.[2] The lack of a clear understanding of the significance of technology and its innovation to productivity is regarded by some as a fundamental cause of the puzzle. Thus, any policy formulated with an eye single to

effectively relating to the phenomenon of differential productivity growth and the problems that obtain therefrom might well benefit from being informed about the dynamics of technological change or innovation.

Industrial policy about which there has been much talk of recent is precisely the policy from which an understanding of those dynamics might benefit. Such policy is also precisely the policy of interest which concern about differential productivity growth rates and the difficulties they can cause has made an issue and to which the concluding chapter refers.

"Industrial policy" at present unfortunately pertains more to the debate over the best course of action to be followed in addressing the United States' long-term industrial problems than a body of action taken or not taken by government.[3] At issue is the role of government in addressing these problems. The proposals of industrial policy aim at three major goals: improving the economy's overall performance; meeting foreign competition; and assisting different levels of productive organization adjust to economic change. How these goals are to be pursued with respect to government's role breaks down into three alternatives. The current policy framework can be left intact. Current policies which relate to industrial growth could be reformed. A new industrial policy institution could be established. The first alternative basically presumes that markets have the capacity to determine for a community the best composition of its economic activity. Both the other two alternatives involve increased government intervention though the second alternative of informing current policy is more extreme. Given a connection between innovation and productivity, much

of the debate which so extensively characterizes what the policy previously is about might well be cleared if the dynamics of the innovative process were better comprehended.

The above discussion of policy in many ways has the features of a definition and well it should. Precision of definition is a requirement for coherence and unambiguity in any investigation. This treatment of policy thus makes for timely transition to the close of this introduction in which several other terms used in this investigation are defined. This serves to insure that uncertainty and ambiguity as to the meaning of the concepts associated with those terms is reduced to the smallest possible degree.

A working definition of the term technology itself is also certainly in order. Technology is regarded simply as a body of knowledge pertaining to the making of tools and the development of skills required to use them. It is concretly manifested in the form of various artifacts or tools designed for certain purposes, the performance of which can be observed.

Technological or technical change or innovation for purposes of this investigation are regarded as interchangeable terms. Such terms refer to the phenomenon whereby through the process of tool combination, technology autogenically transforms itself into an increasingly comprehensive body of knowledge which permits humankind "to do things, do more things, and do all things better."[4]

ENDNOTES

CHAPTER I

1. D. Mowery & N. Rosenberg, "The Influence of Market Demand upon Innovation: A Critical Review of Some Recent Empirical Studies," Research Policy (Spring, 1979) Vol. 8, pp. 102-53.
R. Nelson & S. Winter, "In Search of a Useful Theory of Innovation," Research Policy (Fall, 1977) Vol. 6, pp. 36-76.

2. R. Nelson & S. Winter, "Growth Theory from an Evolutionary Perspective: The Differential Productivity Puzzle." The American Economic Review (May, 1975) Vol. 65, pp. 338-44.

3. The Industrial Policy Debate (Washington, D.C.; The Congressional Budget Office, 1983) pp. xiii-xvii.

4. C. Ayres, The Theory of Economic Progress (Kalamazoo: New Issues Press, 1978), p. xiii.

CHAPTER II

REVIEW OF THE LITERATURE

Definitions of technology are often stated broadly. One may speak of an object of material culture, an artifact, or the pool of accumulated knowledge by which some community achieves its material ends. Some specificity is gained when that pool of accumulated knowledge refers materially to the tools and skills employed in achieving those ends and that such knowledge, by virtue of accumulating, undergoes change not merely due to accretion but more importantly, transformation. Yet, from a formal point of view such definitions are most difficult and often impossible to usefully operationalize. Thus, formal concepts of technology are relatively sparse. This is particularly disconcerting to economists who concern themselves with the behavior of a community and often its individual members with respect to the material ends toward which it and they strive, ends whose realization is a possibility only because of the community's technology. Though an inseparable link betwixt a community's technology and its conduct of economic activity is widely acknowledged, the sparsity of formal conceptions of the former has rendered the incorporation of same into economic analysis problematic in all but the most specialized (and often unrealistic) cases, e.g., static analysis. This deficiency is most glaring when economic analysis addresses itself to the growth, or more accurately, morphogenic growth, of a community's economy. In so doing, the relative security of static analysis must be abandoned and the view of a community's economic activity as a process or on-going enterprise adopted.

Interest in a community's technology and its relationship to a community's material productivity has distinguished history amongst modern economists beginning with Adam Smith.[1] The first chapter of his Wealth of Nations is devoted for the most part to the discussion of technological advance and productivity. It is worth noting, however, that other classicals such as Malthus, Ricardo, and Marx may have missed the significance of technological advance though this is not to necessarily imply that Smith entirely did not.

Malthus' essay on the population and its effect on the prospects for future societal improvements argued for a natural tendency of population growth to outstrip all possible means of subsistence. The race was fated to endure an ever-recurring cycle of famine decimating its population, whereupon the population would rebound only to subject the race to another round of famine. Ricardo perceived the existence of factors operating in an economy which, in combination, worked to the disadvantage of capitalists relative to landowners by shrinking the portion of surplus going to profits even as the surplus being generated increased. At the same time, wages going to those who labored were inexorably depressed to the subsistence level. Paradoxically, only the landowners absolutely benefited from the capital accumulating behavior of the capitalists. Marx apparently understood technological improvement in terms of capital biased combinations of production factors. The selection of such combinations was prompted by the need of the capitalists to reduce the pressure of ever rising wages against their profit margins. The introduction of machinery is a labor-saving strategy. The effect of its introduction is to also stymie rising wages