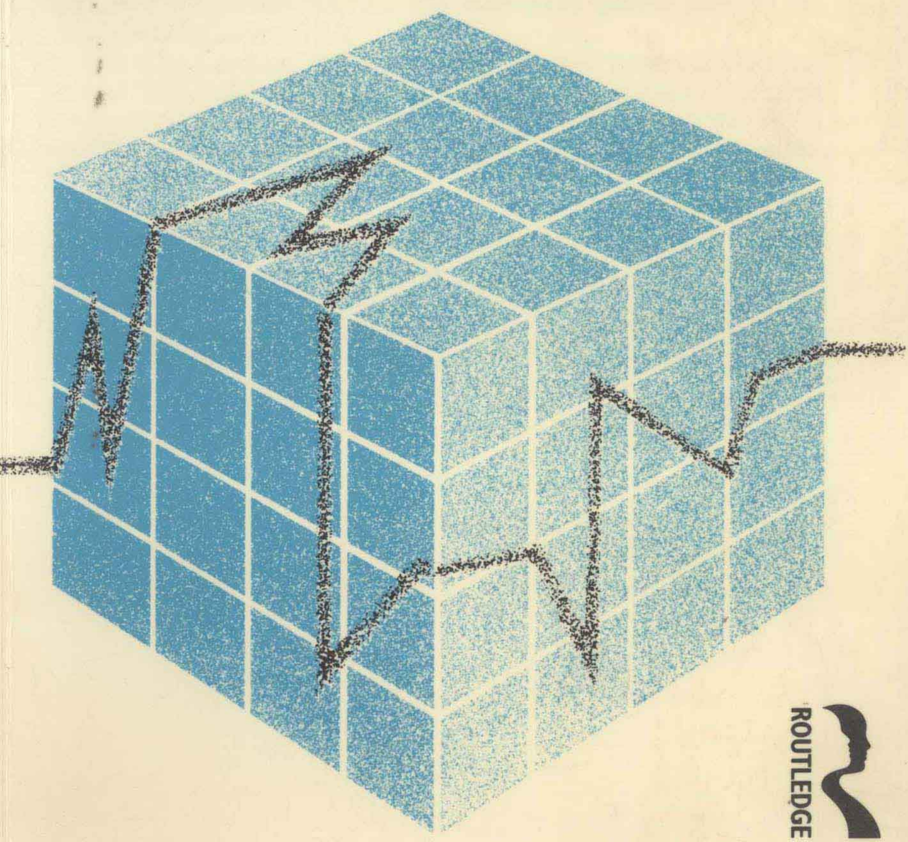
THE THEORY OF TECHNOLOGICAL CHANGE AND ECONOMIC GROWTH

Stanislaw Gomulka



ROUTLEDGE

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Stanislaw Gomulka

London and New York

To Joanna and Michael

First published 1990
by Routledge
11 New Fetter Lane, London EC4P 4EE

Simultaneously published in the USA and Canada
by Routledge
a division of Routledge, Chapman and Hall, Inc.
29 West 35th Street, New York, NY 10001

Printed and bound in Great Britain by Mackays of Chatham PLC, Kent

British Library Cataloguing in Publication Data

Gomulka, Stanislaw
The theory of technological change and economic growth.
1. Technological development. Economic aspects
I. Title
338.06

ISBN 0-415-03692-5
ISBN 0-415-05238-6 pbk

Library of Congress Cataloging in Publication Data

Gomulka, Stanislaw.
The theory of technological change and economic growth / Stanislaw Gomulka
p. cm.
Includes bibliographical references.
ISBN 0-415-03692-5
ISBN 0-415-05238-6 (pbk)
1. Technological innovations—Economic aspects. 2. Economic development. I. Title.
HC79.T4G655 1990
338′.064—dc20 89-77047
CIP

The Theory of Technological Change and Economic Growth

The last two centuries have witnessed sustained technological innovation which by historical standards has been unique in two respects: it has been unusually intense and its variation between nations and types of economic activity has been remarkably large. This book surveys the empirical evidence and the numerous theories of technological change and economic growth in an attempt to provide a unified empirical and theoretical framework for interpreting this intensity and variation. Part I deals with the invention–innovation–diffusion process at the level of firms and industries. It seeks to develop the microfoundations for the macro-oriented analysis of Part II. Central to that macro analysis are two hat-shaped or bell-shaped relationships. One of these describes the change over time of the innovation rate in the technology frontier area (TFA), the part of the world that is technologically most advanced. The other describes the innovation growth paths in the countries outside the TFA.

The wide empirical microeconomic basis and historical perspective of the book places it in the tradition associated with such economists as Schumpeter and Kuznets. However, the book attaches great value to theoretical insight, and this places it in the modern tradition.

Stanislaw Gomulka is Reader in Economics at the London School of Economics. Educated in Poland, he has taught at the University of Pennsylvania and Aarhus University and has held visiting and research appointments at the Netherlands Institute for Advanced Studies and Columbia, Stanford and Harvard Universities.

Acknowledgements

The original invitation to write this book came from Mervyn King of the LSE, and I owe him much for the advice he offered at the initial, formative stage of the project, and for his subsequent encouragement. The task was difficult to accomplish well: to write a monograph which would deal with central issues of the field and which could also serve as a textbook. A large part of the first draft of the book was written at the Netherlands Institute for Advanced Studies in Wassenaar, and I wish to thank the directors and staff for their help. I have benefited much from the comments of several of my LSE colleagues on the various chapters of the book. I wish to acknowledge in particular the suggestions of David de Meza and Mark Schaffer. Alan Jarvis and Ruth Jeavons of Routledge and Christine Sharrock of Omega Scientific were most helpful with their willingness to accept last-minute changes and for seeing the work through its various publication stages.

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Part Two Macroeconomics of Innovation, Technology Transfer, and Growth

Part one

Microeconomics of invention, innovation, and diffusion

Chapter one

Preliminary concepts and relations

The first three chapters of this book are introductory. They are intended primarily to familiarize the reader with some of the economic concepts that will be needed later in the book. The first such preliminary concept is that of the production sector, which will be presumed to consist of production units called firms or enterprises and to be distinct from the sector consisting of consumption units called households. We shall have little to say about the household sector. The innovation activity and the growth of the productivities of inputs in firms, industries, and national economies worldwide will be our primary interest. The production sector is presumed to supply goods of two categories: 'conventional' goods, such as intermediate and investment inputs and consumer goods, and 'progress' goods in the form of new inventions and new skills intended to enhance the welfare-creating capacities of firms and households. Accordingly, in the production sector we distinguish between the conventional activity and the inventive activity. In our introductory chapters we shall identify and discuss the major characteristics of the nature and size of the inventive activity, and the ways in which the latter interacts with and influences the composition and growth of conventional activity. We shall also identify the major stylized facts about world inventive activity, concerning its size and changes over time as well as the distribution among countries and industries in recent times.

Two major definitional qualifications should be made at the outset. One concerns the distinction between the production sector and the household sector. It should be noted that if the enjoyment which we derive from the consumption of goods or from work is seen as one of the (ultimate) goods that economic activities provide, then households themselves should be viewed as production units, especially since in addition to enjoyment they also supply labour services, spiritual experiences, and recreation, as well as conventional goods of the do-it-yourself variety. This is clearly a valid point; it actually led William Nordhaus and James Tobin in 1972 to propose a wider measure of the net effect of economic activity than the widely used net national product (NNP). Their so-called measured economic welfare (MEW) concept attempts to take proper account, in addition to NNP, of the value of leisure, the value of the non-market services of the household sector, and the environmental costs of production, among other things. In our analysis of technological innovation and economic growth it is not conceptually essential to exclude the household sector completely from the production activity. It is only for the well-known reasons of statistical convenience or necessity that the measures of national product that are commonly used exclude the contribution of the household sector. We shall also use these measures and, to that extent, we shall usually restrict the notion of the production activity to its conventional meaning.

The 'black' and 'parallel' economy is another part of the production activity where there are serious measurement problems. We shall make the convenient assumption that it is a constant fraction of the total production activity. However, if the shifts in the distribution of resources between this and the observable sector were large they could seriously disturb the quality of the published output and productivity data, something which some economists suggest actually took place in the 1970s. We have to keep this possibility in mind when using the data, and only if reliable information permits take account of the unobservable economy in our attempts to measure the innovation rate and economic growth of the total production activity.

Production processes, techniques, and technology

Production of goods in any individual enterprise involves combining different kinds of primary inputs, such as unskilled labour and natural resources, with intermediate inputs, such as semi-fabricated materials and energy, and with the services of skilled labour and fixed capital. Production is often a very complex operation, but it can be broken down into many distinct standard operations, some or all of which may take place simultaneously. These are called *production processes* or *activities.*

Following Leontief (1947) and Morishima (1976), we can represent the whole system of processes for each enterprise by a tree. In the tree shown in Figure 1.1, there are four processes. In process (i) inputs 1, 2, and 3 are combined to produce good 8, in short (1, 2, 3) → (8). There are two alternative methods of obtaining good 9: (ii) (3, 4, 5) → (9) and (iii) (5, 6, 7) → (9). In

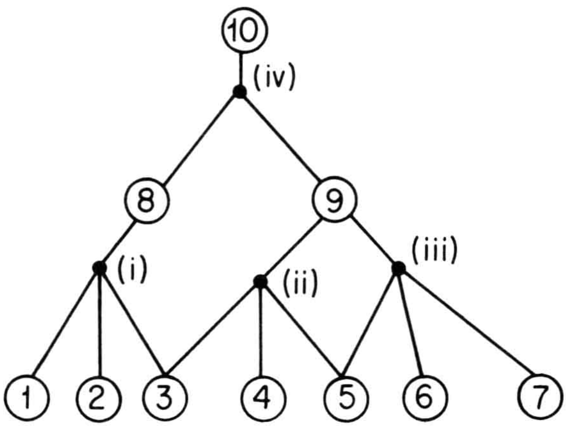

Figure 1.1 Geneology of production. An enterprise with four processes and two alternative methods of producing one final good.

process (iv), which represents the next stage of production, goods 8 and 9 are themselves used as inputs to produce 10, the final output of the production unit. Since product 9 can be obtained by employing either process (ii) or process (iii), two alternative methods of producing good 10 are available to our firm in Figure 1.1, one involving processes (i), (ii), and (iv), and the other involving processes (i), (iii), and (iv). These different methods of producing the final good or goods are called *techniques*, and the set of all techniques available to a firm is its *technology* in the narrow sense.

A process may also require a management input, and this requirement would be reflected in the process's list of inputs. When several processes are involved, we may need someone in the firm to know that they are in fact available and to be able to make the best selection from among them. We include this higher level of organizational and management knowledge in our concept of technology in the broader sense, or simply technology. Consequently, our technology set includes not only purely technological processes reflecting different ways of combining inputs, but also organizational processes reflecting different ways of combining the processes themselves. The outputs of organizational processes are services which may not be sharply defined. For conceptual convenience we can imagine that to each technique of production there corresponds one organizational process with the necessary services of the firm's management and related staff and other resources as its inputs but with zero outputs.

How do we define technology at the industry level? Suppose that an industry consists of several independent firms producing the same final good. Some of the firms may know a method of producing the good that is still unknown to all the other firms. Our definition must respect the fact that technology is firm-specific. Therefore the industry's technology is defined as the collection of all the firm-specific technology sets, each of which contains the production techniques of one firm in the industry. An enlargement of the technology set for any firm, even if it has occurred through the interfirm diffusion of the existing technological knowledge within the industry, would then also represent an enlargement of the industry's technology set. We adopt a similar definition of technology for any higher level of aggregation, including national economies and the world economy.

In centrally planned economies firms have a considerable degree of autonomy, but not full organizational independence. A group of firms is typically organized into an association, associations are organized into a sector headed by a ministry, and sectors are organized into an economy headed by the government. It is a hierarchical structure with each level capable of influencing other levels, especially those below. The association's technology set must therefore be defined to include, in addition to the firm-specific sets, a process or processes pertaining to the organizational activity of the association's head office. This activity could be conducted in a number of ways, and any choice of conduct would be reflected in the quantities of the final outputs and inputs of the association as a whole. The same procedure can be used in the treatment of individual ministries and the government as a whole.

Efficient techniques and technological progress

Whatever the level of aggregation, any enlargement of the corresponding technology set represents, by definition, a *technological change.* However, not every enlargement of the technology set represents what we should like to call technological progress. Inefficient techniques – those which with the same inputs produce less of one or more outputs, or those which require a greater quantity of inputs to produce the same outputs as some other techniques – should not be selected for use whatever the prices of the relevant inputs and outputs, with the exception of cases in which some of the inputs can, like air, be obtained free of charge. Any addition of an inefficient technique to a firm's technology set would, in our terminology, represent zero technological progress for that firm. We define any technique that is not inefficient as efficient, and we say that *technological progress* takes place when a firm's subset of efficient techniques is enlarged or when the newly arrived technique(s) dominates one or more of the existing efficient techniques so that the latter become inefficient. If a firm replaces one efficient technique by another, we cannot be certain that technological progress has taken place, except in the obvious case when the old technique would become inefficient after the acquisition of the new one.

Production processes involve many inputs and one or more outputs. If a process requires that the proportions in which the inputs to be used and the outputs to be produced are fixed, then the process can be fully described by the underlying input–output coefficients. We simply select one of the outputs and take the quantity of the selected output as a measure of the scale on which the process is to be operated. This scale is sometimes referred to as the intensity of the process. Therefore the input–output coefficients for the process in question are the quantities of the inputs and the other outputs per unit of that particular scale or intensity.

However, in practice these input–output coefficients are rarely fixed. To begin with, the rates at which workers operate their machinery and the intensity of their work are rarely fully technologically determined, but are instead a product of conventions or a subject of negotiations between workers and management. As such, these rates are inevitably dependent on particular traditions, institutions, and motivations of all kinds. The resultant input–output coefficients in part mirror the human environment in which the production process takes place. A process which is efficient in one environment may thus be inefficient in another. This is one reason why technological change itself is also culturally dependent. There are many other reasons. In fact there are good grounds for suspecting that this interdependence between technological change and the cultural, as well as the institutional, characteristics of a nation is one of the most powerful causes of the observed wide variation in the rates of innovation and economic growth among nations and, to some extent, over time. We shall refer to this interdependence many times throughout the book.

The other major parameter giving rise to variation in input–output coefficients is the scale on which a production process is operated. Processes need not be scale-specific, but neither can they be operated on any arbitrary scale. Usually the description of a process includes also the specification of the range of scales on which it is most efficient to use it. One form of technological progress has been precisely the invention of large-scale processes to supply goods at a low cost for large-volume markets. Indeed, the shift towards a large-scale technology has been one of the dominant trends of the world's industrial revolution, until now at any rate, partly in response to the enlargement of markets: from local to regional, to national, and now to worldwide. The advent of microelectronic devices and sophisticated robots may end or even reverse this trend. Yet it would still remain true to say that a change in the scale of operation may often turn an inefficient process into an efficient one, and vice versa. Consequently the rate of assimilation of a particular technique, and hence the rate of technological progress, may also depend on the size of the market which an industry supplies.

If the number of all products is finite, and for practical purposes this is what we usually assume, the maximum output that a firm can obtain from different combinations of inputs forms, in the product space of all inputs and outputs, a multidimensional sphere called the firm's *production possibility frontier* or production function. The addition of an efficient technique moves this frontier or function outwards, and thus any such movement signifies the presence of technological progress within the firm.

Allocative efficiency, *X*-efficiency, and relative rationality

A switch from one technique to another involves a change in the composition of production processes. Thus, from a purely engineering point of view, the switch represents a change in technology. However, if both techniques were known to the firm before the change took place, then, in our terminology, they would belong to the same technology set and, as the switch merely represents a movement within the set, no technological change would have been involved. Technological change would take place if the new technique represented an addition to those already in the technology set. Moreover, the change would represent technological progress if the new technique were efficient.

In our quest for clear and consistent terminology care must be taken to see to it that we do not end up with a straitjacket structure of concepts incapable of dealing with interesting real-life situations. Such a situation may arise when techniques which are actually operated become, as experience accumulates, better known to the operating workers. If this increasing familiarity and accumulating experience are mirrored in changing input–output coefficients, these techniques should be presumed as changing over time. Such experience is usually technique related; it will be partly lost if the firm makes a switch from one technique to another. We