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ON *ECONOMICS AND TECHNICAL CHANGE**

BY

D. B. J. SCHOUTEN AND P. J. F. G. MEULENDIJKS**

1 REVIEW

On the occasion of the fiftieth anniversary of the Dutch Postal Payments System, Dr. Heertje was asked to write a book on the economics of technical development. His work resulted in a Dutch study of which this text is the English translation. The English edition differs from the Dutch in that it introduces the literature that has appeared since the publication of the original edition in 1973 as well as some new ideas which Heertje has developed since then.

Dr. Heertje has chosen to write a basically non-mathematical book dealing with the history of technology, production theories and the significance of technical development to economic growth, monopoly power and economic policy. Since the author's intention was to trace the history of the relevant economic theories and of the underlying background of technical development, he has chosen a mainly chronological approach. He relaxes it on occasions, notably in his analysis of the work of past authors by modern methods, because he believes this will be a good way to evaluate the usefulness of analyzing the past. Moreover, he feels that the use of new concepts to describe old ideas can help clarify the argument.

The author explains in the introduction (Chapter 1) his concept of technical change, a concept based on the idea of the production function used in the modern neo-classical theory. Dr. Heertje makes a clear distinction between technical change in the broad sense – meaning the development of technical possibilities – and technical change in the narrow sense – meaning additions to the stock of technical knowledge. Both concepts can be defined more precisely by the neo-classical concept of the production function. Therefore we refer to Chapter 5, devoted to the precursors of production theory. It recalls the

* Review of and comments on: Arnold Heertje, *Economics and Technical Change*, Weidenfeld and Nicolson, London, 1977. Pp. xii + 334.

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period 1870–1920 in which the neo-classical theory of production was founded and the Cobb-Douglas production function was more frequently used. Disregarding Von Thünen, it was the first time that the idea of production as a relation between input of capital and output of products in combination with technical constraints was formulated in terms of a mathematically specified production function. It was Schumpeter who first gave a stimulus to the identification of a shifting production function with technical change, thus creating the possibility to distinguish between a shift along the curve (substitution as a result of a change in the relative factor prices) and a shift of the curve itself (technical change). If the production function is viewed as an expression of the range of technical possibilities, then technical change corresponds to a shift of the production function, and vice versa. The possibly incomplete picture of technical development thus produced can perhaps be more readily identified in the light of new production functions. Here the great value of the set-theoretical production theory for the analysis of technical development becomes apparent. It is discussed in Chapter 8.

To a certain extent, Chapters 2 and 3 on the classical school and Karl Marx set the tone of the whole book. Dr. Heertje explains that two diametrically opposite pictures can be presented, *i.e.* one of the harmony and spontaneous order which the classical economists saw in economic affairs and one of the disharmony and concentration of power with its disintegrating influence, which Marx believed to be central characteristics of capitalist economies. More specifically, a distinction may be made concerning the historical development in theoretical thinking about the phenomenon of technical change. The various lines of thought seem to be inspired merely by the question of whether or not technical change leads to unemployment, a question which gave rise to the so-called compensation theory. Classical adherents of this theory, such as Steuart, Smith and Ricardo, were convinced that there were sufficient mechanisms within the framework of pure competition to effect reemployment of the displaced labour force. Their classical counterparts, such as Malthus and Marx, did not have the same confidence in this flexible way of adjustment.

Dr. Heertje argues that the present renewed interest in technical change can be explained by the similar idea that it is the nature of technical change to cause structural unemployment, even though economic theory and practice seem to have succeeded in avoiding serious cyclical problems and in finding reasonable solutions. Consequently, more attention is being paid to optimal utilization of available sources. Because existing technological conditions should be considered as restrictions on the optimal use of the factors of production, the state of technology and its change have again become focal considerations in theoretical and practical thinking.

The author has devoted special attention to Karl Marx's ideas about technical change and in this context he introduces Samuelson's famous two-sector model of Marx's theory. He again demonstrates the specific assumptions regarding technical change on which Marx's negative prophecies might have been based. Alternative model specifications enable him at an early stage to indicate the various classifications of technical change. It appears that Marx was dealing with Harrod's neutral technical change causing the same consequences as an increasing input of labour within the framework of a neo-classical production function and its corresponding well-known assumptions. However, as we all know, in Marx's case the degree of accumulation falls short. The redundant labour force that has been displaced as a result of that neutral technical change cannot be completely reemployed.

Dealing with the history of technical change (in Chapters 4 and 7) up to and since 1900, Dr. Heertje arrives at an interesting conclusion. He points out that before 1900 most inventions preceded scientific activity although every invention was of course the fruit of scientific abstraction. After 1900, research was based on scientific insights which subsequently led to technical change. The process of technical change from then on should be considered as a continuous process of technical development in which the range of technical possibilities increased gradually. However, we should not forget that revolutionary change in economic and social life could then, as it can now, be brought about only by the creative power of individual researchers.

At the end of Chapter 4 Dr. Heertje observes that, with the exception of Marx, the economist's interest in the phenomenon of technical change as a driving force in economic and social life is of very recent origin.

The whole of Chapter 6 has been devoted to Schumpeter. It becomes clear that Schumpeter was only incidentally concerned with technical development as apart from innovations. He makes a distinction between the two. In contrast to Marx's objective point of view, Schumpeter denied the relevance of inventions to innovations. His subjective point of view shows an overwhelming interest in the entrepreneur's innovative activity causing the dynamics of the economic system by means of '*Neue Kombinationen.*'

The micro-economic and macro-economic production theories are the subjects of Chapter 8 and Chapter 9, respectively. The 'micro-economic' chapter is devoted merely to the nature of the different interpretations of the production function and to the aforementioned use of the set-theoretical production theory. The 'macro-economic' chapter deals with the existence of the macro production function. More especially, these chapters discuss the existence of the *ex ante* production function. Problems arising here, such as those of specification due to lack of data and of the uncertainty inherent in the process of production in

combination with phenomena such as 'learning by doing' and diffusion of technical knowledge, are also examined. Moreover, attention is given to Kaldor's views on the impossibility of making a clear distinction between substitution and technical change. The crux of the matter is whether or not a clear distinction can be made between a shift along the production curve and a shift in the production curve itself. According to Kaldor, the first case implies the second one because an introduction of new machines will imply the introduction of new processes. The author's detailed discussion on the concept of neutral technical change leads once more to the general impression that this idea may be significant only within the framework of a separate model specification.

In Chapter 10 Dr. Heertje deals more thoroughly with the relationship between technical change and economic growth. He devotes special attention to the various possibilities for specifying technical change within the neo-classical model of growth. In particular, he sets Kaldor's alternative of embodied technical change to be incorporated in his 'technical progress function,' against technical change to be incorporated in the production function as a trend factor. Both possibilities are open to the same objection, namely that they introduce a complication by not separating technical change from the accumulation of capital. In the course of the main line of reasoning, it becomes very clear why and how the subject of technical change in economic theorizing developed from exogenous, disembodied, embodied-to-endogenous technical change. In the latter case, the nature and magnitude of technical change depend on economic factors, *e.g.*, they are generated by changing relative factor prices and investments in research and development. Within the latter context Dr. Heertje analyzes the relation between technical change and monopoly power. He appears to be an adherent of a modern semi-liberal market-oriented social-economic order. Schumpeter considers the competitive climate to be the driving force of capitalism. The author is of the same opinion and considers a certain degree of competition to be the force needed to create a social and psychological climate in which growth and change can flourish in society. Therefore, he prefers the various intermediate variants of the puzzling market form of oligopoly (Chapter 11) to the market form of perfect competition or pure monopoly. They satisfy the sufficient conditions for an innovative market performance, *e.g.*, sufficient inclination and ability to invest in research and development. However, it remains true that the process of technical development needs guidance and control because of its influence on so many aspects of social life, to the extent that it may easily overpower the individual firm, multinationals included. In Chapter 12 the author states his belief that the active role in this process played by the central government is fully justified, particularly in view of the effects of technical change on employment and the environment.

The last chapter of this study is devoted to the shifting frontiers of economics. Technical development cannot be viewed as a phenomenon outside the sphere of economics; it is an endogenous element of economic theory and policy, which means that the frontiers of economics have definitely shifted. The demand-oriented macro-economic interest in problems of stagnation has been replaced by a renewed attention to the classical task of economic science. The analysis of the causes of quantitative and qualitative growth in the possibilities of satisfying the wishes of mankind by innovating a way to utilize scarce resources is again relevant to the present situation. This implies a shift of theoretical thinking to the field of micro-economics of technical innovation.

2 GENERAL COMMENTS

Our first comment on this study is that it touches on an overwhelming number of subjects which the author has further elucidated with copious notes to the final pages. For this reason we recommend it as a useful survey of the literature on the relation between economics and technical change. However, for the same reason, we have been obliged to restrict our review to some of Heertje's main lines of thought.

The author's assigned task of filling a gap in the literature for a varied readership of undergraduates, postgraduate students and working economists, as well as those doing research in the field of technical development (p. ix), has *resulted in many woolly arguments.* Now and then the author becomes *rather vague and* sometimes *muddled,* as when he confuses the classical and neo-classical interpretations of the concept of capital in Chapters 2 and 3, devoted respectively to the classical economists and to Marx.

Although Dr. Heertje has chosen to write a basically non-mathematical book he sometimes uses algebraic and geometrical tools in order to elucidate his line of analytical thinking. However, this *striving for more clarity fails* when he deals, *e.g.*, on p. 29 and 30, with an algebraic and a graphical version of the model underlying the compensation theory in classical economics. There is no agreement between the two versions. Moreover, strangely enough, the graphical version represents only two equilibrium cases which imply instability on the product market. The corresponding situation on the labour market must be similar, although the author's aim is to show by means of the graph how classical economists might have been led to assume that workers displaced as a result of mechanization were reemployed via the price mechanism. There is also a discrepancy on p. 86 and 87,[1] between the algebraic and the graphical versions of the

1 E. von Böhm-Bawerk, *Kapital und Kapitalzins, II,* Positive Theorie des Kapitals, Vol. 1, 4th ed., Jena, 1922, and K. Wicksell, *Über Werk, Kapital und Rente nach den neueren national-ökonomischen Theorien,* Jena, 1893.

translation by Heertje of Wicksell's presentation of Von Böhm-Bawerk's theory of the roundabout production route.

The author makes an error in his interpretation of Wicksell's 'second case,' in which the length of the roundabout production route (*i.e.* the production time) is such that the rate of profit r is maximized. It is worthwhile to verify such errors. As a case in point we give in section 3 a more elegant interpretation of the gist of Von Böhm-Bawerk's and Wicksell's theory of the optimum production period and reformulate both versions, having concluded our general comments.

There are many arguments in the book that the reader is expected to accept at their face value; this is certainly true of the final section of Chapter 9 on macro-economic production theory, *e.g.*, where the author discusses, on p. 170, 171 and 172, the portrayal of technical change occasioned by a shifting empirical macro-economic production function. He argues that 'such empirical research on technical development is left hanging in the air' since there is an insufficient basis of micro-economic considerations. He mentions Johansen, who 'has recently published an important book, in which,... the connection between *ex ante* and *ex post* micro- and macro-economic production functions is demonstrated on an impressive scale.'[2] It will be difficult for those who are familiar with the subject to understand the arguments put forward by Heertje in support of this judgement. Those who have only a nodding acquaintance with it can hardly accept them at their face value.

As we have already said, the book is overburdened with an overwhelming range of subject matter, with the consequent risk that some of the existing literature on these subjects may be insufficiently represented. This is the case, *e.g.*, in his discussion on V.E.S. functions on p. 128, 141 and 198.[3]

We have already mentioned the author's defense in Chapter 12 of the active guidance and control of technical development by the central government. On p. 263 he argues that this is necessary, because 'technical development upsets equilibria (if these are attained at all) and aggravates situations of disequilibrium mainly by the economies of scale it produces. In this respect, it is a source of continuous uncertainty.' This governmental 'guidance and control of technical development should be carried out in close consultation with individual compan-

2 This study has been reviewed and commented upon in: P. J. F. G. Meulendijks, 'L. Johansen, Production Functions; An Integration of Micro and Macro, Short Run and Long Run Aspects, Amsterdam-London, 1972,' in: *De Economist*, LXXII (1974), pp. 169–172.

3 Good surveys of recent literature on this subject can be found in: T. de Biolley, *A New Class of Neo-Classical Production Functions with Corresponding Investment Behaviour*, Ceruna, Namur, 1972, and in: J. E. J. Plasmans, *Production Investment Behaviour*, Tilburg University Press, 1975.

ies.' The need for participation can be satisfied by designing suitable procedures for decision-making.' And on p. 264 the author argues that 'it is possible that we may thus achieve the eventual convergence of initially different value judgements.'

However, Heertje gives no explanation as to why and how such centrally guided and controlled policy can actually succeed. In fact, in Chapter 11 he proves that this is not the case. Moreover, this proof is self-evident in present policy decision-making at the various levels of our socio-economic system. It is precisely the main reason why many economists have emphasized again and again that, if we want to maintain the socio-economic order that exists in the Western world today, we must maintain or restore the sufficient market mechanisms which will effectively regulate the economic process. In our opinion this is also true of the regulation of technical development. Too much governmental interference inevitably means that too few timely signals are given to indicate what jobs are necessary and how they should be carried out. For the same reason we reject the author's idea of increasing the effectiveness of economic policy in this field by more intensive mutual consultation at micro level. We repeat: the greatest opportunity to increase, both in the qualitative and the quantitive senses, the possibilities for satisfying the uncoerced wishes of mankind lies in the market-oriented socio-economic order.

Of course, we need on the one hand sufficient market mechanisms and on the other hand the imposition of effective restrictions with regard to problems of employment and the environment. But we believe that these restrictions can be achieved by adequate global policy measures.

We shall develop our ideas in a more exact way *by means of the next model* of a closed economy, including a labour market and a product market. It will enable us to evaluate short-term as well as long-term consequences of two important phenomena with respect to the question of whether or not technical change leads to unemployment. That is, our so-called *conjunctural-structural* model allows for the analyses of the absorptive power of the economic system with respect to the consequences of technical development. For the sake of the next exercise we use the pure supply model idea with respect to the product market, whereas the labour market will operate under an imperfect regime. So, for the labour market, the market clearing function of wages is partially taken over by the rate of unemployment if this is temporarily needed.

Note however that the model permits a large measure of flexibility; it can be used for the analysis of the consequences of demand or supply dominancy at the two markets, depending on the particular situations at hand. In order to avoid the well-known problems of non-linear model specification, the variables in our model are formulated in terms of relative differences with respect to the path of

exponential or equilibrium growth. The symbols that stand for absolute values are denoted by '˜', whereas the subscript 'o' relates to the equilibrium values of the variables. Without this subscript they relate to the real or actual values. Exogenous variables have a dash underneath. So we define, $\tilde{x}$ being the real or actual value and $\tilde{x}_o$ being the corresponding equilibrium value of a variable, the relative difference x of the same variable as:

$$x = \frac{\tilde{x} - \tilde{x}_o}{\tilde{x}_o}$$

In the equilibrium neighbourhood the first difference of x is approximately equal to the extra rate of growth of this variable with respect to the preceding period *i.e.*:

$$\Delta x = x - x_{-1} \approx \frac{\tilde{x} - \tilde{x}_{-1}}{\tilde{x}_{-1}} - \frac{\tilde{x}_o - \tilde{x}_{o-1}}{\tilde{x}_{o-1}}$$

Now we can formulate the model:

1. National employment is determined by the level of national production and the exogenous labour productivity push:

$$l = y - \underline{h}$$

2. Definitional relation between national production, national consumption and national investment:

$$y = \gamma c + \sigma i$$

3. National consumption all derives out of labour income in the same period:

$$c = l + w$$

4. Nominal investment today is determined by nominal profits yesterday:

$$i + p = y_{R-1} + p_{-1} \Rightarrow i = y_{R-1} - \Delta p$$

5. The real wage-rate per worker today is determined by the real wage-rate per worker yesterday, by the level of national employment, by an exogenous change in labour productivity and by an exogenous wage-push:

$$w = w_{-1} + \beta l + \underline{\Delta h} + \underline{\Delta p_l}$$

6. Definitional relation between national income, labour income and profits:

$$y = \lambda(l + w) + (1 - \lambda)y_R$$

7. The effect of relative differences in investment on the national capital stock (= national production capacity):

$$k = k_{-1} + \frac{\sigma}{\kappa}(i_{-1} - k_{-1})$$

8. The rate of utilization of national production capacity in terms of equilibrium capacity:

$$-sb = y - k$$

9. Price-changes are determined by the rate of utilization of national production capacity:

$$\Delta p = \xi(-sb)$$

Greek symbols stand for the following ratios and parameters:

$\gamma = \tilde{c}_o/\tilde{y}_o = 0.5$: consumption share of total demand (= national production)

$\sigma = \tilde{i}_o/\tilde{y}_o = 0.5$: investment-output ratio

$\kappa = \tilde{k}_o/\tilde{y}_o = 1$: capital-output ratio

$\lambda = \tilde{t}_o \cdot \tilde{w}_o/\tilde{y}_o = 0.5$: labour share of national income

$1 - \lambda = \tilde{y}_{R_o}/\tilde{y}_o = 0.5$: capital share of national income

The imperfect competition on the labour market and the perfect competition on the product market are represented by a choice of the numerical values for:

$\beta = 2$: elasticity of real wages with respect to employment;
$\xi = \infty$: elasticity of prices with respect to the rate of utilization of capacity.

The model has 9 equations and 9 unknowns and therefore is determined. In this context our special attention is turned to the unknowns with respect to national capacity, national production, national employment and the real wage-rate per worker. For brevity's sake we shall formulate the reduced form of the capital stock variable in the numerical scheme and use it for calculations of the numerical consequences for the other variables caused by:

1. a permanent labour productivity push without wage pushes, and
2. a permanent labour productivity push with incidental, but not permanent wage pushes.

Both productivity pushes are Harrod's neutral technological change pushes, *i.e.* only of the labour-saving kind.

TABLE 1 – PERMANENT LABOUR PRODUCTIVITY PUSH OF 1 PERCENT IN PERIOD 1, WITHOUT PERMANENT WAGE PUSHES.

	PERIOD								
Variables	0	1	2	3	4	5	6	7 = 1	Trend
$\underline{h}$	0	1	1	1	1	1	1	1	1
$\underline{p_l}$	0	0	0	0	0	0	0	0	0
$\underline{k} = k_{-1} - k_{-2} - 0.5\Delta\underline{p_{l_{-1}}} + \underline{h_{-1}}$	0	0	1	2	2	1	0	0	1
$y = k$	0	0	1	2	2	1	0	0	1
$l = y - \underline{h}$	0	−1	0	1	1	0	−1	−1	0
$w = 2\sum l + \underline{h} + \underline{p_l}$	0	−1	−1	1	3	3	1	−1	1

TABLE 2 – PERMANENT LABOUR PRODUCTIVITY PUSH OF 1 PERCENT IN PERIOD 1 WITH AN INCIDENTAL, BUT NOT PERMANENT, NEGATIVE WAGE PUSH OF – 2 PERCENT IN PERIOD 0.

	PERIOD			
Variables	0	1	2 = 1 = 3 *etc.*	Trend
$\underline{h}$	0	1	1	1
$\underline{p_l}$	−2	0	0	0
$\underline{k} = k_{-1} - k_{-2} - 0.5\Delta\underline{p_{l_{-1}}} + \underline{h_{-1}}$	0	1	1	1
$y = k$	0	1	1	1
$l = y - \underline{h}$	0	0	0	0
$w = 2\sum l + \underline{h} + \underline{p_l}$	−2	1	1	1

The most important conclusion we can draw from *the proceding numerical results* must be that they represent only two of the numerous possibilities which will *confirm our thesis that the sufficient market mechanisms can effectively regulate any disturbance of the economic process, including that of an incidental, but permanent shock due to technical change, as e.g. the introduction of the chip may be.* Of cource, in spite of the presence of sufficient market mechanisms, postulated in the model by $\beta = 2$ and $\xi = \sim$, Table 1 shows that a regular business cycle with a periodicity of six years cannot be avoided. The main reason for this is a lack of timely signs of such shocks and thus the absence of available instruments to absorb them immediately. This first numerical case shows that the

incidental, but permanent relative increase of labour productivity causes unemployment and a relative decrease of the real wage-rate per worker in the first period. However, in period 2 this situation is ameliorated and period 3 shows the opposite picture. National capacity and production are not affected in periods 1 and 6, but in the other periods they are affected in a positive manner.

From the long-term (= trend) results we see that the absorptive power of the economic system is sufficient. National capacity and production take care of the same level of employment as we had in the initial equilibrium situation. The real wage-rate per worker is ameliorated up to the degree that corresponds with the positive increase of labour productivity.

We suggested already that well-functioning market mechanisms, together with the possibility of timely policy decision-making, can ensure a sufficient absorptive power in our economic system, not only in the long run but also in the short run. Table 2 shows such a possibility for absorption of the business cycle. However, it supposes a policy decision-making unit that will be strong enough to get the timely signals of occuring shocks and care for a timely enforcement of the alternative jobs that are necessary. In our case this enforcement consists of organizing an incidental, but not permanent, negative wage push in the period preceding the period in which the timely recognized occurance of an incidental, but permanent, labour productivity shock takes place. Only in the first period of successful action (period 0) does real wage-rate per worker deteriorate. Apart from this, national capacity, production and the real wage-rate per worker can ameliorate up to the same degree as the relative increase of the labour productivity. The level of employment remains at its equilibrium value without any disturbance because timely planned wage policy measures would be responsible for timely planned extra investment. The trend results are the same as we already saw for period 1 of Table 2 and equal the trend results of Table 1.

However, our concluding remark must be that the picture presented in Table 2 is only a picture of a paradise. Today, as we all know, the assumed timely signals and powerful policy decision-making units do not exist in the Western economic systems. So we must return to Table 1 and conclude that the well-functioning market forces are the only instruments available in order to get a sufficient answer to the question of what alternative jobs are necessary and how they should be carried out. Therefore it is a great pity that we must recognize the actual fact that the deficiently functioning labour markets in many West European countries are so persistent that nobody can entertain the hope of a recovery of the sufficient absorptive power with regard to technological pushes as we saw in the past.

3 REFORMULATION OF AND COMMENTS UPON DR. HEERTJE'S INTERPRETATION OF VON BOHM-BAWERK'S AND WICKSELL'S THEORY OF THE OPTIMUM PRODUCTION PERIOD

Let us first summarize Dr. Heertje's *correct written* interpretation of Von Böhm-Bawerk's capital theory. On p. 84 he argues that:

> ... the 'subsistence fund' of this theory is similar to the classical wage fund. The subsistence fund makes it possible to follow roundabout routes of production, and the larger the fund, the longer these routes can be. If well-chosen roundabout production methods are followed with the aid of capital goods, more or better consumer goods can be obtained than by direct production. But the longer this roundabout route of production is, the slower will be the growth of production. The consumer goods produced at the end of such a route must be set against the disadvantage of lower consumption for the duration of this longer production period, which Von Böhm-Bawerk called a 'sacrifice to time.'

After presenting his algebraic version, Dr. Heertje establishes in Figure 4, p. 87 a diagram showing a graphical means of finding the best production period 'at which the rate of profit r is maximized.' We shall use this diagram in order to judge the correctness of the author's graphical and algebraic interpretation of Von Böhm-Bawerk's and Wicksell's production period. (See the upper diagram in our Figure 1 below.)

First we shall formulate the algebraical model which, in this context, correctly interprets Von Böhm-Bawerk's and Wicksell's situation. As Dr. Heertje does on p. 86, we assume a static situation involving a given number $\bar{l}$ of employees, an annual per capita production q, a given annual wage per head $\bar{w}$ and a length of the roundabout production route (*i.e.* production time) t. Von Böhm-Bawerk's theory can be reduced to a relationship between q and t. The function involved increases with increases in t in a degressive way, *i.e.*, the marginal returns decrease. Assuming that production equals total income, we can formulate the model as follows:

$$q = q(t) \qquad \text{: annual per capita production} \tag{1}$$

$$\frac{y}{t} = q \cdot \bar{l} \qquad \text{: annual total income} \tag{2}$$

$$k = \tfrac{1}{2} t \cdot \bar{w} \cdot \bar{l} \qquad \text{: circulating capital invested} \tag{3}$$

$$\frac{y}{t} = \bar{w} \cdot \bar{l} + \frac{r}{t} \cdot k \qquad \text{: definitional relation} \tag{4}$$

The difference between Heertje's model and this one is in the definitional relation (4). The author created some confusion for us by identifying the average annual total profits with $r \cdot k$, instead of $\frac{r \cdot k}{t}$. This may be one of the reasons for his modest interpretation of the *upper diagram* in our Figure 1 below, which is an exact reproduction of Heertje's diagram on p. 87.

In order to understand the importance of the two graphs in the figure for finding the optimum length of the roundabout production route we shall reduce the algebraical model to two equations as follows. From equations (1), (2) and (4) we derive:

$$q(t) = \bar{w} + \frac{r \cdot k}{t \cdot \bar{l}} \tag{5}$$

and rearranging equation (3) we obtain:

$$\frac{2k}{\bar{w} \cdot \bar{l}} = t \tag{6}$$

Equation (5) shows that average annual per capita production equals the sum of the average annual wage per head and the average annual per capita profits. Equation (6) shows that the number of times of paying out the annual total labour income equals the number of years involved in the roundabout production period.

In contrast to the author's previously mentioned interpretation of the optimum length of the roundabout production route, the correct one should be: *that length of the roundabout production route at which the average annual rate of profit* $\frac{r}{t}$ *is maximized*, instead of the integral rate of profit r.

The algebraical model can be reduced to one equation by rearrangement and substitution of equation (5) and (6) as follows:

$$q(t) - \bar{w} = \frac{r}{t} \cdot \frac{\bar{w}t}{2} \tag{7}$$

or $r = f(t) \cdot t$ and

$$\frac{r}{t} = \frac{2q(t)}{\bar{w}t} - \frac{2}{t} = f(t). \tag{8}$$

If equation (7) conforms exactly to the exponential curve drawn in the upper diagram of Figure 1, and taking the origin of the abscissa in point B (along which the roundabout production time is plotted), it is easy to verify that equation (8) exactly corresponds to the concave downward curve in the lower diagram of this figure. For the sake of clarity and simplicity we may set the value of the given wage per head $\bar{w}$ at 2 and denote it by the segment OB in the upper diagram. Now it will be clear that the rate of profit r is plotted along the ordinate in the upper diagram, with its origin in point B.

Taking account of the given value $\bar{w} = 2$, we are able to derive from equation (7) as well as equation (8) the necessary and sufficient condition to be satisfied in order to deal with the optimum roundabout production route situation, *i.e.*, within our context this condition implies:

$$\frac{\mathrm{d}q(t)}{\mathrm{d}t} = \frac{r}{t} = \frac{q(t) - 2}{t} \tag{9}$$

In verbal terms, condition (9) shows that the average annual rate of profit is maximized when it equals the marginal returns of the annual per capita production in t. This becomes clear if one realizes that in our context the latter value equals the marginal rate of profit in t, *i.e.*, $\frac{\mathrm{d}r}{\mathrm{d}t} = \frac{\mathrm{d}q(t)}{\mathrm{d}t}$; the relevant domain stretches from point G to point F in the upper diagram of Figure 1. In the same diagram we can see that the tangent ED coincides with the radius vector BD. Therefore, the segment OA denotes the optimum length of the roundabout production period. The lower diagram depicts the relation between the average annual profit $\frac{r}{t}$ and the roundabout production time. The various values on the $\frac{r}{t}$-axis correspond to the tangent values of the angle between the varying radius vector BD and the varying length of the abscissa BF in the upper graph. The maximum $\frac{r}{t}$-value is obtained if t = OA and equals the value of the segment HA in the lower graph.

From both diagrams in Figure 1, and realizing that equation (6) implies $t = \frac{k}{l}$ if $\bar{w}$ is set at 2, *we may conclude that the correct interpretation of Von Böhm-Bawerk's and Wicksell's roundabout production theory can be suitably explained in terms of the traditional way of searching for the optimum capital/labour ratio in neo-classical production theory.*

It only remains to mention the author's remark on p. 87 that he can use the

upper graph in Figure 1 to demonstrate the relationship between Von Böhm-Bawerk's and Wicksell's production period and Helmstädter's interpretation of Harrod's neutral technical change. He actually uses it on p. 165, and strangely enough he identifies the segment OE in the graph as the optimum rate of interest (profit), defined in the author's manner as we noted before. However, from our Figure 1 it is easy to verify that in the present optimum situation:

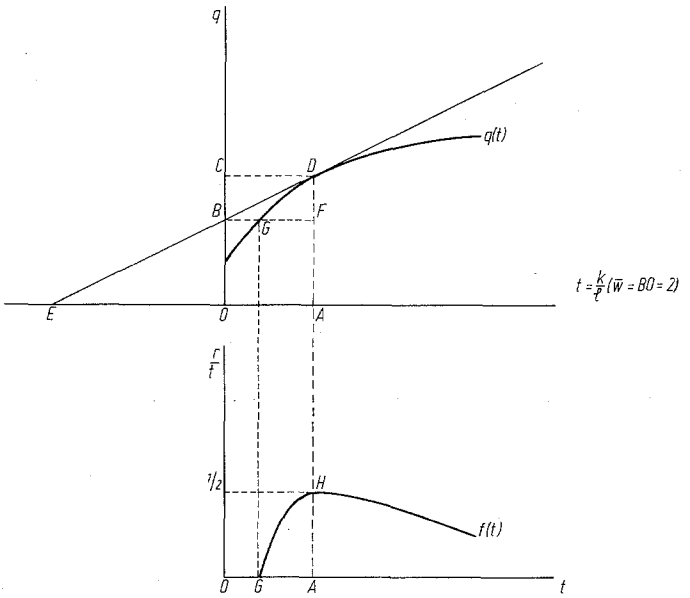

Figure 1.

the absolute value of $\frac{BO}{EO} = \frac{DF}{BF}$ or $\frac{\bar{w}}{EO} = \frac{r\bar{w}}{2 \cdot t}$, which implies: $\frac{1}{EO} = \frac{r}{2 \cdot t}$.

If in equation (3) the circulating capital invested k had been defined for a total time of t instead of an average time of $\frac{1}{2}t$, EO should be identified in this case as the *reverse* maximum value of the average annual rate of profit $\frac{r}{t}$.

4 CONCLUDING REMARKS

This study provides a general insight into the rich history of technical change and its place in the development of economic thought. It gives a detailed account of the enormous quantity of literature on the different aspects of the subjects that has appeared since the time of Adam Smith. It is obvious why this flood of

literature is bound to increase in the future. Therefore Professor Heertje's idea of making a comprehensive synthesis of the evolution and the present state of the economic analysis of technical change was a courageous one. His aim of reaching such a varied readership in one and the same volume was risky and, in our opinion, the task was too difficult. Perhaps there should have been two versions of the book, each suited to a different category of readers, be they undergraduates, post-graduate students, working economists or researchers. It might even have been better for the author to confine himself to the interests of one of these categories only. The result might well have been greater conformity in basic methodology and subjects than is now the case. These considerations are particularly important since, without such special basic methodology, deep discussions of any subject must inevitably fail. The same considerations were stimuli for the construction of our own model at the end of Section 2. It allows for a more exact analysis of the important question about the absorptive power of an economic system with regard to the consequences of labour-saving technological pushes (whether or not being of exogenous origin).

Nevertheless, the way in which Dr. Heertje has acquitted himself of his assigned task deserves the appreciation of all those who are interested in the field of economics and technical change.

Summary

ON ECONOMICS AND TECHNICAL CHANGE

The article is divided into four sections. The first consists of a review of a few main lines of Heertje's thoughts on the relation between economics and technical change. It appears that Dr. Heertje has chosen to write a basically non-mathematical book dealing with the history of technology, production theories and the significance of technical development for economic growth, monopoly power and economic policy. The general comments in the second section make it clear that his study is an excellent survey of the literature on the subject. It covers an overwhelmingly large number of topics and includes copious notes at the end. However, the author's assigned task of filling a gap in the literature for a varied audience of undergraduates, post-graduate students and working economists as well as those doing research in the field of technical development inevitably proved to be too difficult. It means that many conclusions have to be accepted at their face value. On the contrary, at the end of the second section of the *present* article a 'CS' model is constructed that allows for a more exact analysis of the important question about the absorptive power of an economic system with regard to the consequences of labour-saving technological pushes. The third section deals more fully with the author's treatment of Von Böhm-Bawerk's roundabout production theory. Improvements are suggested in this section as well as in the concluding fourth section.