

Harrod on the classification of technological progress. The origin of a wild-goose chase *

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“The whole search for an equivalence of the “two definitions” is, in a sense, a bit of a wild-goose chase, since they are taking up the whole problem in different (though, it may well be, complementary) ways.”

(Hicks to Harrod, 30 January 1963)

1. Introduction

From the 1930s to the 1970s a number of economists were engaged in debates on the classification of technological progress into neutral, labour- or capital-saving inventions. A first definition was proposed by Pigou in *Economics of Welfare*, distinguishing between improvement leaving unaffected, increasing or reducing the ratio of capital to labour in the industry to which it applies (Pigou 1924, p. 632). In 1932 Hicks proposed instead that inventions are neutral if they increase in the same proportion the marginal products of capital and labour (Hicks 1932, pp. 121-22). Finally, in 1948 Harrod defined as neutral the inventions that leave the capital-output ratio unaffected at a given rate

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of interest. The debates which followed mainly regarded Hicks's and Harrod's definitions; it was asked, in particular, under which conditions they are equivalent.

Alternative definitions usually reflect different purposes and/or theoretical perspectives. Some commentators have remarked that Harrod and Hicks were pursuing different aims, the former being interested in the conditions that would not disturb the equilibrium rate of growth of the economic system, the latter in the conditions that would not alter the income distribution between capital and labour.¹ However, the matter was not pursued further, and a number of questions still remain to be answered. In particular, it is striking that all attempts to study the equivalence of the two definitions assumed at the outset that both Harrod's and Hicks's notions were to be applied to a function expressing the amount of production in terms of capital and labour inputs; the solution on which commentators eventually agreed was that the two definitions were equivalent if a specific production function was assumed, the so-called Cobb-Douglas.

Curiously, none of the discussant remarked that this theoretical set-up was consistent with Hicks's procedure but was extraneous to Harrod's approach, which was not based on the production function but – although somewhat confusedly – on the Austrian concept of capital and production.² The purpose of this essay is to throw some light onto the latter aspect, by examining the origin and development of Harrod's notion of neutrality in its context, illustrating how it was characterised, what conceptual framework it presupposed, and what function it played within his dynamic economics.

2. Harrod's 'moving equilibrium'

Harrod first dealt with the problem of the character of inventions in his book *The Trade Cycle* in 1936. His trade cycle theory was based on

¹ The debate in its broad outline is briefly surveyed in Section 7 below.

² The controversies on capital at the end of the 1930s and in the 1960s exposed logical flaws in both the notions of aggregate production function and average period of production, on which Hicks's and Harrod's definitions of 'neutral inventions' were based. These will not be discussed here, as this essay is primarily concerned with the historical aspects of the origin of the debates on the classification of technological progress.

the interaction of the Keynesian multiplier and the acceleration principle. According to the multiplier doctrine, an increase in investment determines increase in income, which in turn is partly spent thus generating new income and so on, in a convergent process depending on the proportion of leakage at each stage. According to the accelerator, net investment in fixed capital takes place when there is a prospected increase in demand that cannot be faced by existing equipment. The actual increase in investment depends on the rate of interest, which determines which of the available technologies will be chosen by entrepreneurs.

In this scheme, an increase in income determines an increase in demand, which stimulates investment and in turn creates additional income. One of the possible outcomes of this process is growth at a constant rate. Harrod, however, stressed that such a state of moving equilibrium is unstable, as a slowing down of the rate of growth would amplify itself and eventuate in a depression. The trade cycle is an inevitable consequence of the fact that the factors on which the intensity of the multiplying and accelerating effects depend vary as income grows: in particular, as people become more affluent they tend to save a higher proportion of their income, thereby diminishing the multiplier and determining a decrease in the rate of increase in income, and so on cumulatively.

Technological change is one of the several degrees of freedom in Harrod's system that may affect its rate of growth, as inventions could alter the amount of additional capital necessary to obtain the supplementary output to meet the prospected increase of consumption.³ In this context, the most natural notion of 'neutrality' regards the constancy of the capital/output ratio⁴ at a given rate of interest. If this were the case, technological progress would not affect the growth process; if the capital/output ratio increased, more investment would be triggered by the same prospective increase in consumption thereby

³ The use of a more capitalistic method of production could, for instance, compensate for an increase in the propensity to save (Harrod 1936, p. 94; see Keynes to Harrod 12 April 1937, in Keynes 1973, p. 172).

⁴ More precisely, in *The Trade Cycle's* theoretical set-up one should consider the ratio between capital and output of consumption goods. In his later writings, however, Harrod decided to avoid the complications arising out of the distinction between capital and consumption goods (see Harrod to Keynes, 21 August 1938, in Keynes 1973, p. 328) and directly related investment and increase in income, so that the relevant factor became the ratio of capital to total output.

further boosting economic growth; and conversely in the opposite case.

These reflections were a side issue in Harrod's thought, as the cause driving investment was the increase in consumption, while the rate of interest and technology were factors affecting only the intensity of this link. Since Harrod was more interested in the fundamental trade cycle mechanism rather than in developing the details, in his book one can only find a cryptic sentence at the end of a footnote (p. 91). It is hardly surprising therefore that none of the commentators referred to the original argument. Nevertheless, Harrod revealed to Hawtrey that he "did a great deal of work on this, behind the scenes so to speak" (31 January 1937); and indeed the surviving correspondence with Kahn and Keynes confirms that Harrod carefully explored the issue. After his book was published, Harrod raised the point again in correspondence with Hawtrey, Keynes and Joan Robinson, before expounding his definition of neutral invention at length in *Towards a Dynamic Economics* (1948). This eventually gave rise to a number of attempts to compare Harrod's and Hicks's notions.

3. Refining a definition

Harrod's correspondence with Kahn and Keynes in March 1935 indicates that he was experimenting with the newly learned acceleration principle.⁵ In particular, he was trying to disentangle the effects on total investment of a change in technical methods and of a change in demand.⁶ Although it is not clear how he was proceeding (only Kahn's and Keynes's parts of these exchanges survive), he was certainly referring to the Austrian economists' terminology: he used expressions such as 'lengthening of the period of production' and 'increase of roundaboutness', and he explicitly (but unwarrantedly, in Keynes's view) tried to attribute to the Austrians the distinction he

⁵ The principle was discovered between 1914 and 1917 by Aftalion, Clark and Bickerdicke; Harrod, however, learned of its possible application to trade cycle theory only in October 1934 from the typescript of Haberler 1934.

⁶ Harrod seems to have raised the issue in correspondence with Hicks, with reference to Hicks's notion of neutrality; the evidence, however, is indirect only, as only Hicks's reply survives (4 November 1932).

was looking for.⁷ This terminology was carried over through all the debates on this topic in which Harrod took part, although he never fully specified its meaning.

Harrod also attempted a preliminary definition of neutral inventions, but from the extant fragments it is difficult to understand what he was driving at.

In *The Trade Cycle* – which was concluded early in 1936 – Harrod did not examine the problem at length. Nevertheless, with hindsight the reader can see that it was all there: while discussing the character of the moving equilibrium, Harrod pointed out that the introduction of techniques of 'a more capitalistic design' would alter the pace of growth and disturb equilibrium. The definition runs as follows: "A method of production is said to be more capitalistic, i.e. to involve the use of more capital goods per unit of output, if, *at a given rate of interest* on the capital goods, the interest charge per unit of output is higher" (Harrod 1936, p. 91n).

After the publication of *The Trade Cycle*, Harrod also found useful Hawtrey's distinction between 'widening' and 'deepening' of capital,⁸ to which, however, he added the following specification:

"Suppose owing to an increase of efficiency (including organization) one man could mind 10 machines instead of 5 and there were no other production costs. The labour cost of utilizing the machines would have halved. But unless we suppose that labour is becoming more efficient at using machines at a greater rate than it is making them – and the normal assumption unless there is a proviso to the contrary, must be that labour is becoming more efficient at the same rate in using machines as in making them – the cost of making machines must have fallen to half. This means that tho there are now 10 machines per man instead of only 5 the use of capital has not "deepened."⁹ The interest element in the cost of the final commodity will be, subject to the rate of interest not hav-

⁷ Kahn to Harrod, 6 and 23 March, 6 April 1935; Keynes to Harrod, 21 and 28 March 1935.

⁸ "The widening of the capital equipment means the extension of productive capacity by the flotation of new enterprises, or the expansion of existing enterprises, without any change in the amount of capital employed for each unit of output. The deepening means an increase in the amount of capital employed for each unit of output" (Hawtrey 1937, p. 36).

⁹ The same argument had already been put forward in Harrod (1934, pp. 292-93).

ing altered, the same as before (cf. last sentence of my footnote on p. 91)" (Harrod to Hawtrey, 31 January 1937).

Harrod thus confirmed the view expressed in his book, which privileged the *cost* component of investment. An exchange of view with Keynes, however, soon induced him to re-examine his own approach and led him towards a new definition of neutral invention.

In his Galton Lecture, Keynes listed three factors on which the demand for capital depends: *i*) the average number of consumers (population), *ii*) the average level of consumption and *iii*) the average period of production (capital technique) (Keynes 1937, p. 126). Harrod was in the audience, and later wrote down his impressions. His comments mark a temporary step backwards in his own thought. He questioned that an increased demand for consumption goods necessarily absorbs any savings, as it may be due to an improvement in efficiency all round, both in the capital and in the consumption goods industries. On the basis of the same argument put forward to Hawtrey, Harrod concluded that as the additional capital was produced more efficiently it could be paid for out of the funds set aside to replace the lower amount at the old cost.

"I put the matter thus. More capital can only be employed (i) if the quantity of the other factors employed increases (your point (i)) (ii) if the quantity of capital employed per unit of the other factors employed increases. This clearly covers the whole ground. I claim that my point (ii) is wholly covered by your point (iii). If more capital is employed per unit of the other factors I say that the productive process has become more capitalistic" (Harrod to Keynes, 17 February 1937).

Harrod's approach here is curiously pre-Keynesian, as it emphasised relationships that he himself left in the background after reading *The General Theory*.¹⁰ As Keynes correctly noted, in fact, Harrod was assuming falling prices as efficiency increases, while Keynes was assuming rising income: "If my income rises as a result of an invention, that does not make the excess of my income over my consumption any

¹⁰ Harrod argued in theoretical writings and in policy debates in terms of prices and banking policy until early 1935 (see for instance Harrod 1934 and 1935). Then he read Keynes's book in proofs (July and August 1935), and shortly afterwards abandoned the old scheme and wrote *The Trade Cycle* in terms of quantities rather than prices.

the less saving" (Keynes to Harrod, 18 February 1937). Keynes was also not satisfied with Harrod's new definition of more capitalistic production process with reference to the ratio of capital to other factors of production, preferring instead to consider the demand for capital with respect to output.¹¹

Harrod recognised that Keynes was right regarding their respective assumptions, and concluded:

"I believe as a matter of fact that your definition of "amount of capital" and not mine is implicit in my Ch. II sec. 4. But I perceive that my book needs more articulation at that point" (Harrod to Keynes, 19 February 1937).

4. Harrod and Joan Robinson on the classification of inventions

Harrod soon found an occasion to further articulate his reflections on technological progress. In her 1937 volume of *Essays in the Theory of Employment*, Robinson had adopted Hicks's classification of inventions and defined a neutral invention as one that leaves the ratio of marginal productivity of capital to that of labour unchanged when the relative amounts of the factors are unchanged (Robinson 1937, p. 132). Harrod reviewed the book for the *Economic Journal*, and took the occasion to criticise some aspects of the production function approach and to propose the alternative classification that was implied in the argument of *The Trade Cycle*. In particular, Harrod attacked Robinson's use of the concept of elasticity of substitution, which "is introduced at a point where its propriety is not apparent and the conditions at the margin to which it is supposed to relate are not sufficiently clearly explained",¹² and remarked that her classification of in-

¹¹ Keynes pointed out, on grounds of the data supplied in his lecture (Keynes 1937, p. 128), that "assuming a steady rate of interest, the nature of inventions is such as to require a greater amount of capital per worker, but that the increase is not much more than in proportion to the output. If the amount of capital required for this purpose falls short of our normal savings, then we have to try and stimulate the use of capital by a substantial reduction in the rate of interest" (Keynes to Harrod, 18 February 1937).

¹² Keynes agreed with Harrod's comment on Joan Robinson's "treatment of the effect of inventions. Your line of approach seems to me to be the right one. I am not

ventions "is ambiguous without the provision of a precise measure of the volume of capital", for it was not clear whether a unit of capital should "be conceived as waiting in respect of a unit of commodities per unit period or waiting in respect of a unit of labour" (Harrod 1937, pp. 328-29). To avoid this ambiguity, Harrod proposed

"to divide inventions into those which *at a given rate of interest*, and an infinitely elastic supply of capital at that rate, increase, leave unchanged or diminish the length of the productive process" (*ibid.*, p. 329).

Harrod claimed that his new definition would enable one to solve Robinson's problem of determining the effect of each kind of invention on the distribution of income:

"By adopting the procedure which I have suggested, the problem may be solved very simply. Since the rate of interest is taken to be constant, the share of labour will fall, rise or remain constant according as whether the invention lengthens, shortens or leaves unaltered the length of the productive process" (*ibid.*).

Harrod's review generated an extensive correspondence with Robinson (Harrod's side is unfortunately lost), which eventually induced her to write the first recognised contribution to the saga of the comparison of different notions of neutral inventions (Robinson 1938).

Robinson was intrigued by Harrod's alternative classification, and struggled to express the conditions under which the two notions coincide with respect to the problem of the effect of inventions on the distribution of income. The difficulty began with the very first step, as Robinson rightly observed that Harrod claimed both that neutral inventions raise "the m[arginal] p[roductivity] of labour and capital in the same proportions" and that they "(with constant rate of interest) [leave] the period of production unchanged". Moreover, she raised some doubts "about measuring capital by the period of production" (Robinson to Harrod, 7 May 1937). From Robinson's next letter it would seem that Harrod explained that he measured roundaboutness in terms of capital per head, while she refers to the total stock of capital (Robinson to Harrod, 13 May 1937).

quite sure what assumptions the elasticity of substitution method requires, but I think they would be found to be inappropriate" (Keynes to Harrod, 12 April 1937, in Keynes 1973, p. 174).

Having cleared up the terminological difficulties, Robinson tried to compare the domains of application of Harrod's, Hicks's and Pigou's definitions by mapping the respective regions along a unidimensional line (the dimension was not specified, but was presumably the relative shares of capital and labour of the national dividend) (Robinson to Harrod, 30 May 1937). Such an attempt was bound to fail (failure was admitted in Robinson's letter to Harrod of 8 June 1937), for Harrod's notion left out a fundamental ingredient for determining the distribution of income along the lines dictated by the production function approach: the production function itself was missing, or at least some assumption regarding either the elasticity of substitution between capital and labour or variations in the relationship between prices and productivity.¹³ The success of Robinson's further attempt therefore required consideration of the induced variations of the relative productivities of capital and labour, which led to the conclusion that Harrod's neutral case

"would correspond to a case where in my language the invention is neutral (Hicks) and $\eta=1$ [η being the elasticity of substitution between labour and capital]. But equally a whole range of cases in which the invention is capital or labour saving (Hicks) and η correspondingly greater or less than 1" (Robinson to Harrod, 8 June 1937; see also Robinson 1938, p. 141).

Having taken this step, it is not surprising that Robinson's solution revived Harrod's result (as expressed to Hawtrey and Keynes a few months earlier) in terms of costs and productivities,¹⁴ but substituted

¹³ Robinson expressed the matter as follows: "What I have been trying to get at all along is this - there are two factors to be considered, a) the nature of the change in technique, b) the change of proportions of the factors required to give equilibrium with a given rate of interest. You have tried to boil these two into one" (Robinson to Harrod, 8 June 1937).

¹⁴ As it results from the following passage of Robinson's letter of 8 June 1937, Harrod must have presented her as well with his reasoning in terms of productivity, but this time he did not fail to specify the assumption underlying it: "You say in case of neutral invention & constant rate of interest if prices fall in proportion to increase of productivity money value of capital per man remains constant. This involves an increase in *physical* capital per man. Money capital per man is constant, money income of capital is constant, real income of capital has increased in proportion of increase in productivity. The capital goods purchased by a sum of money have increased in proportion to productivity and m.p. of capital in both money terms and real terms is the same as before, i.e. equal to the rate of interest".

Harrod's assumption of prices falling in proportion to increasing output with the assumptions allowing to formulate the distribution problem with the aid of the production function:¹⁵

"An iso-elastic rise in the average productivity curve of capital means that there is a certain proportion, say k , such that if the amount of capital per unit of labour is increased by k , output also increases by k . Thus an invention which raises the average productivity curve iso-elastically, that is, a neutral invention in Mr. Harrod's sense, has the same effect as an increase in the supply of labour, in the ratio k , with unchanged technique. A neutral invention is thus seen to be equivalent to an all-round increase in the efficiency of labour. A capital-saving invention is one which improves efficiency in the higher stages of production relatively to efficiency at lower stages, and a capital-using invention is one which brings about a relative increase in efficiency in the lower stages" (Robinson 1938, p. 140).¹⁶

This exchange exasperated both participants (Robinson to Harrod, 8 June 1937), and the debate concluded with "each preferring his own method" (Robinson to Harrod, 16 June 1937); Robinson remained with the impression that Harrod's method was "simpler" than [hers] simply because it doesn't deal with the problem" (Robinson to Harrod, 12 June 1937). What went wrong?

The origin of the mutual incomprehension seems to lie in the fact that their systems of classifications of inventions were originally worked out to face different problems: Robinson was interested in the effect of inventions on the distribution of income, and analysed tech-

Robinson, however, did not think this assumption to be enough to solve her problem: "Well, all right. But this situation cannot be fully described by referring to the nature of the invention. It also brings in the m.p. of capital curve - i.e. you have to take into account how much physical capital per man changes to give equilibrium".

¹⁵ It should be noted that Robinson's was not the first attempt to couch Harrod's intuition in terms of a production function. James Meade translated the first draft of Chapter II of Harrod's *Trade Cycle* into a production function homogeneous of the first degree, which he used to examine the factors affecting the intensity of the acceleration principle (Meade to Harrod, 12 January 1936, "Note I").

¹⁶ It is worth noting that after Harrod shifted his attention from changes in output towards changes in income, the formulation of the problem embodied at the outset the assumptions on the relative movements of prices and productivity ensuring that the definition of neutrality also implies "that the productivity of labour embodied in machines is raised in equal measure with that of those engaged on minding machines" (Harrod 1948, p. 23).

nical progress in terms of the capital/labour ratio; Harrod's approach was worked out to tackle the quite different question of the amount of capital necessary for the production of the output required to satisfy the expected demand for consumption goods; the level of employment and the relative productivities at the margin of capital and labour are thus not directly involved by such a view of technical progress. The trouble was therefore not only that of the assumptions necessary to switch from one notion to the other, but primarily laid in the nature of their respective problems. In the first place, Harrod's notion was worked out in a *dynamic* context to take account of the effects of *continuous* changes in technology in the face of equally continuous variations in the other determinants and in the rate of interest, while Robinson was dealing with the once-over effect of technology changes on distribution. Second, Harrod's notion of neutrality regarded the persistence - *ceteris paribus* - of a moving equilibrium, and the variables to be considered therefore had to express a *proportion* rather than absolute values.

Harrod was aware of these differences in their general perspective. However, he tried to extend the use of his own definition to Robinson's problem. But attempts to solve one problem in terms of the instrument devised to face the other question would obviously have required some additional assumptions widening the domain of application of the instrument or bringing the problem to be solved back to the domain of application of the analytical tool. This is what both Harrod and Robinson tried to do, but apparently with limited success. As a result of this exchange, however, Robinson wrote a paper on "The classification of inventions" (1938) where she analysed the properties of Hicks's and Harrod's definition of neutrality by means of a production function, and drew her conclusion in terms of the elasticity of substitution between labour and capital (this, the reader will remember, was the starting point of Harrod's criticism), thereby establishing the ground for the following debate on technological change.

5. Harrod and Kaldor on roundaboutness

Harrod had a further occasion to argue out the determinants of capital intensity. In fact he discussed with Kaldor a draft of "Capital in-

tensity and the trade cycle", where Kaldor examined "what meaning, if any, can be attached to the investment period concept [...] and how this 'investment period' – i.e. the method of production actually chosen by producers – is determined" (Kaldor 1939, p. 41). As to the first question, Kaldor argued that the notion of 'investment period' provides no more than one of the possible measures of the ratio of capital to labour; he concluded that it would be better to drop the use of expressions such as 'investment period' and 'period of production' altogether, and to adopt instead "some less ambiguous terms, such as the 'degree of roundaboutness of production', or the 'degree of capital intensity'" (*ibid.*, p. 42). As to the second problem, on the ground of an analysis at the margin of costs and efficiency of capital in various circumstances, Kaldor concluded that the answer

"ultimately depends on the nature of the forces which limit the scale of investment of the representative firm. If this scale is limited chiefly by the limitation of the firm's output-market, by the amount the firm expects to be able to sell, the rate of interest will be the important factor; if it is limited chiefly by the scarcity of funds at its disposal, the main influence will be the level of prices, relatively to wages" (*ibid.*, p. 51).

Here it is not important to examine Kaldor's reasoning in detail, for the whole discussion turned around Harrod's assertion that increases in the level of wages do not induce substitution of capital for labour or conversely, unless the rate of interest falls. Harrod admitted indeed that in some circumstances a change in the level of wages could trigger a change in interest, but only conceded that changes in the method of production occur as a direct consequence of the variations of interest. In other words, Harrod maintained that there is a fundamental asymmetry between the influence of wages and interest:

"My main point, which I think is often overlooked, may be put simply thus. If real wages are raised for manual workers and the real wages for brain workers are the same, there will be a tendency to use [more]¹⁷ brain workers per unit of manual workers in the productive process. If real wages are raised for manual workers and the rate of interest remains the same, there will *not* be a tendency to use more capital per unit of manual workers. (You might argue

¹⁷ Harrod originally, but obviously mistakenly, wrote 'less'.

that if the rate of interest remained the same and the real rate of wages went up, the real reward for capital had gone up too: it would if you measure a unit of capital as waiting for time t in respect of a unit of labour: but *not* if you measure a unit of capital as waiting for time t in respect of a unit of consumption goods)" (Harrod to Kaldor, 24 May 1938).

In front of Kaldor's incapacity of understanding his point, Harrod restated it several times, for instance as follows:

"If you compare two states of equilibrium and find that the rate of interest in the market or the marginal supply price of capital to the representative firm is unchanged you can say unequivocally that, given also technology unchanged, the degree of round-aboutness will not be altered, whatever has happened to the real rate of wages.

Per contra if the real rate of wages remains unchanged while the rent of land or some other factor (other than waiting) changes, then substitution of that other factor for labour or labour for that other factor will have occurred. This is the fundamental asymmetry. That there is this asymmetry I have no doubt whatever" (Harrod to Kaldor, 31 May 1938; see also letters of 4 and 22 June and 7 August).

Again there was a problem of communication here, as Harrod was not thinking in terms of the *production functions* underlying Kaldor's analysis,¹⁸ but in terms of the *average period of production*, which depends on the roundaboutness of the method adopted which in turn is inversely related to the rate of interest. Harrod could thus conclude:

"What I do say is 1. that a fall in the rate of interest stimulates greater round-aboutness, regardless to what is happening to wages, (I grant that it may work round to cause a rise of wages) and 2. that a rise of wages does not stimulate to greater round-aboutness unless and until its legitimate consequence of a fall in the marginal cost of borrowing has actually taken effect" (Harrod to Kaldor, 7 August 1938).¹⁹

¹⁸ For such a qualification of Kaldor's approach, formulated by himself two decades later, see Kaldor (1960, pp. 6-7).

¹⁹ It should be noted that in the last letter of this exchange Kaldor refused Harrod's approach because of an anticipation of the (now) well-known argument that the "trouble about measuring a unit of capital as a 'unit of labour invested for a unit of

At this point Harrod was thus considering capital intensity in terms of the capital/output ratio to be measured by the average duration of the productive process. At the same time, he was averse to the idea that changes in the wage rate directly affect the degree of roundaboutness, thereby implicitly rejecting the approach in terms of the capital/labour ratio, on which the production function analysis is based.

6. *Towards a Dynamic Economics*

Harrod's reflections on technological progress and economic dynamics were suspended during the war years but were resumed for a series of lectures held at the London School of Economics in 1947 (published the following year as *Towards a Dynamic Economics*). Since the preliminary chapter Harrod considered technological change in the light of the problem "what behaviour of capital is required to be consistent with growth in the other elements, *on the hypothesis that the rate of interest does not change?*" (Harrod 1948, pp. 21-22). Neutral inventions were thus defined as those that would not interfere with the harmonious growth of the whole system, leaving the system unchanged as if no inventions occurred, under the assumption that the system started from that unlikely and unstable position:

"I define a neutral advance as one which, at a constant rate of interest, does not disturb the value of the capital coefficient; it does not alter the length of the production process" (*ibid.*, p. 23).

"A neutral stream of inventions [is defined] as one which shall require a rate of increase of capital equal to the rate of increase of income engendered by it. If the stream of inventions requires capital to increase at a greater rate, then it is labour-saving or capital-requiring; and conversely" (*ibid.*, pp. 26-27).

As a corollary, Harrod pointed out that his definition implies that increments of labour efficiency are homogeneous (the argument he put forward to Hawtrey, Keynes and Robinson in 1937), and that a stream of neutral inventions does not affect the distribution of total

time' [is] that the 'unit of time' relevant here is not real time - hours - but something which itself varies with the rate of interest" (Kaldor to Harrod, 9 August 1938).

national product between capital and labour, provided that the rate of interest does not change (Harrod 1948, p. 23). The latter statement was only justified several years later, when Harrod pointed out that if the rate of interest and the length of the productive process are unchanged, "the proportion of the value of the final product that is to be assigned to interest is unchanged; *i.e.*, the share of capital is unchanged" (Harrod 1961a, p. 301).

Regarding Harrod's definition a number of remarks are necessary. Firstly, at this point of his book Harrod had not expounded the fundamental relationships linking the dynamics of the various magnitudes in his system; the reference to the capital coefficient (the capital/output ratio determining the intensity of the acceleration effect) reveals however that the definition was devised at the outset having a precise theoretical set-up in mind. This, of course, is hardly surprising if one looks at the whole of Harrod's writings on dynamics, but is apt to give rise to misunderstandings if one only looks at *Towards a Dynamic Economics*. And this seems to have been the case for most commentators. Secondly and analogously, it is far from clear at this point why the rate of interest is taken as given: in spite of the emphasis in the statement quoted above, only a few pages later the reader is told that "the rate of interest is assumed to be constant, since that is a simpler assumption than that of a changing rate of interest" (Harrod 1948, p. 27).

Thirdly, Harrod claimed that while Hicks's definition involves various elasticities and other "circumstances quite unrelated to the intrinsic character of the equation itself", his own definition "determines the matter solely by reference to the invention itself". On this point Harrod was certainly illuding himself: the definition of a 'neutral' object is never given in absolute terms, but with reference to a process that is not affected by the 'neutral' thing. Hicks was studying income distribution, and had to define as 'neutral' those inventions not affecting the factors responsible for the division of income between capital and labour - the ratio of their marginal productivities. Harrod's classification is given in terms of the *existing* capital/output ratio, and inventions are pigeon-holed according to how they alter this ratio.

The purpose and characteristics of Harrod's definition become clearer, to the patient reader, only when neutrality is required to do the work for which it was originally planned. In discussing the truis-

tic equation $GC = s$ relating the actual rate of growth of the system²⁰ (G) to the fraction of income saved (s) and the capital coefficient (C), Harrod explained that

“[t]his definition is based on the idea that existing output can be sustained by existing capital and that additional capital is only required to sustain additional output. This follows from the assumption that the capital/income ratio is constant, *i.e.* that the length of the production process is unchanged and this follows from the two assumptions on which we are presently working, namely, (1) that inventions are neutral and (2) that the rate of interest is constant” (Harrod 1948, pp. 82-83).

Ultimately, inventions are neutral in so far as they do not absorb additional savings (*ibid.*, pp. 30 and 32). If they are not neutral, an additional term d (for ‘deepening’) has to be subtracted from the saving part of the fundamental equation describing the warranted rate of growth: $G_w C_T = s - d$ (*ibid.*, p. 96). Harrod is thus referring to technological change both by means of the Austrian (length of the average period of production) and Hawtrey’s (deepening) terminologies, which he seems to have considered as equivalent, but he developed his classification and his theoretical approach bearing in mind the effect of inventions as absorbers of saving suggested by Keynes in correspondence in 1937 (see § 3 above).

7. Production function and technological change: the debate

In the years immediately following the publication of *Towards a Dynamic Economics* and of Domar’s essays on growth (Domar 1946 and 1948), the ‘Harrod-Domar model’ (as it was soon, but inappropriately, renamed²¹) was interpreted in terms of macro-dynamic differ-

²⁰ Harrod distinguished between three rates of growth: the actual rate G , the equilibrium (warranted) rate G_w , and the natural rate G_n , expressing the maximum rate allowed by the increase of population and technological improvements. All these variables change during the cycle and are subject to long-run considerations. A divergence between G and G_w is cumulative (equilibrium is unstable), but is halted from above by G_n , which stops G but not G_w until the latter overtakes the former and initiates the downward phase of the cycle.

²¹ For a comparison of Harrod’s and Domar’s theories see Asimakopulos (1986).

ence or differential equations. Commentators noticed that Harrod had not provided an explicit link between states of his system, but failed to understand that this was an intended consequence of Harrod’s approach. Harrod, in fact, was concerned in the first place with providing an *instantaneous* picture of the set of relationships characterising the state of growth of the system, while only the second stage of his analysis (which he never developed in full) would have taken into account ‘the succession of events’ (see Kregel 1980, pp. 114-17, and Besomi 1996, p. 288). Interpreters thus filled in the missing equation, and debated whether or not the system was stable. Other authors, belonging to the neo-classical school, attributed Harrod’s instability to the rigidity of the capital-output ratio, and developed alternative models where shifts of technique were introduced to resolve the instability problem. Harrod of course never meant to assume a constant acceleration coefficient: it simply looked as fixed because the temporal horizon in the first stage of Harrod’s analysis was an instant.²² Nevertheless, by formulating a growth model using a production function Tobin (1955), Swan (1956) and especially Solow (1956) reopened the way for analysing technological change as shifts of a function expressing production in terms of capital and labour.

The first contribution along that line was proposed by Uzawa (1961), who interpreted Harrod’s definition of neutral inventions as those leaving the marginal product of capital undisturbed at a constant capital-output ratio (thereby inverting the causal relationship), specifying the implications of this definition upon the form of the production function, and confirming Joan Robinson’s result that the Harrod and Hicks definitions are equivalent if, and only if, the production function is of a Cobb-Douglas type. Meade (1961, p. 57) revived Robinson’s result by means of a diagram with two production functions representing technology before and after the change; Ghosh (1980) assumed the Cobb-Douglas condition of equality as his starting point, and represented the two definitions by means of a different kind of diagram (the matter was further discussed by Chiang 1981). Kennedy (1962a and 1962b) argued instead that in a simplified model where technological progress took place only in the consumption sector or were applied to a single improvement, Harrod’s and Hicks’s definitions are equivalent throughout. Asimakopulos (1963) replied

²² The interpretations of Harrod’s dynamics are surveyed in Besomi (1998, § 3).

by qualifying the conditions under which the two definitions are or are not equivalent according to the type of model considered. Other authors later took one or another of these results as proven, and simply cited them in their papers aiming at generalising the domain of application of Harrod's and/or Hicks's definition, e.g. by considering multi-sectors models (Goddard 1970), or to work out other definitions (Birg 1969, Asimakopulos and Weldon 1963, Asimakopulos 1988), or by examining the role of Harrod's neutrality for growth models other than Harrod's own (Whitaker 1970).

A number of authors went beyond the exercise of comparing the attributes of Harrod's and Hicks's definitions. Kennedy (1962b, p. 900) correctly remarked that Harrod was particularly interested in the capital-output ratio as he was concerned with growth theory, and Kennedy and Thirlwall (1972, p. 20) noted that Harrod's and Hicks's definitions were elaborated with very different purposes in view. Blaug (1963, p. 19) and La Tourette (1964, pp. 213-15) correctly pointed out that while Hicks's definition applies to once-over innovations, Harrod's applies to a steady, indivisible stream of improvements. La Tourette took a further step, and recognised that Harrod's world is dynamic, while Hicks's is static (*ibid.*, p. 214). He also noted (*ibid.*, p. 221) that the role of neutral technological progress is to avoid disturbing the moving equilibrium, while Goddard (1970, p. 300) attributed the success of Harrod's definition to the fact that it refers to macro-economic equilibrium.

All the contributions cited in this section, however, considered Harrod's definition in terms of a production function: some attributed it to Harrod himself, others suggested that it was implied by Harrod's method, and the rest simply took it as the most natural way of approaching the problem. This procedure, however, hides the anomaly of Harrod not using the production function like everybody else.

8. Conclusion: roundaboutness and the production function

If Harrod's emphasis on the capital/output ratio is easily understandable in the light of the role that this variable plays in the determina-

tion of the dynamic equilibrium, the reason for his rejection of the use of the production function is much less clear. He certainly did not need to specify any precise assumption as to the production function. The first stage of his dynamics, in fact, is only concerned with a "simultaneous conspectus" of the relationships linking the various (changing with continuity) variables in his system, and in one instant of time technology, expressed as a ratio, is taken as a datum. Harrod did not fully develop stage two, where parameters change along with the evolution of the system and because of exogenous factors. As he could not master the mathematics of functional equations, he failed to specify a rule linking one state of the system to the next, and probably perceived as the only feasible approach that all the calculations were iterated step after step taking account of the new conditions. This distinction into three separate stages of dynamics (the third being policy advice) was not perceived by commentators, who – in spite of Harrod's protest – projected in time his instantaneous equation describing the growth rate (see Besomi 1998, pp. 50-51 and 66). Harrod's treatment of inventions seems to have suffered the same fate, as his definition was also interpreted as applicable to the long-period, in which case either movements along a production function or shifts of the function itself appeared an appropriate concept to commentators.

Harrod, however, seems to have had a more fundamental reason for rejecting the use of a production function. He consistently used instead the Austrian and 'deepening' terminology, and insisted – against Sraffa's criticism of the notion of average period of production (Sraffa 1960, § 48) – that these were the appropriate concepts:

"In favour of the 'period of production' the following points may be made. First, *at a given rate of interest* industries can be ranked as of greater or less capital intensity by the proportion that interest bears to the value of the product (which simply reflects the length of the production period). Secondly, *at a given rate of interest*, improvements can be ranked as capital-saving or capital-requiring by whether they lower or raise the total interest payment as a proportion of the value of the product" (Harrod 1961b, pp. 786-87; see also 1961a, p. 300).

Unfortunately the matter remains far from clear, as the reference to the classification of inventions is circular because of it being formulated in terms of the period of production concept. Nor are

more precise statements to be found elsewhere in Harrod's writings. One is thus left wondering whether Harrod had something precise in mind, or whether he was only instinctively referring to a terminology which he found convenient but which had no precise link to its origin: Keynes's remark (cited in Section 3) that the attribution to the Austrian of this implication of Harrod's terminology was not warranted seems to hold also for the later developments of his thought. The concept of 'production period', in fact, purports to be a measure of aggregate capital per head, and both Joan Robinson and Keynes drew Harrod's attention to this.²³ The concept to which Harrod refers, however, is capital per unit of output. This seems to be another of the numerous cases in which Harrod attached to existing terminology a meaning suitable to his own purposes,²⁴ thereby adding to the confusion.

Harrod's vagueness, however, offers precious indications as to the difficulties involved in extending to extraneous uses notions that were developed for specific purposes. Of this, Hicks was also aware. When he looked back at his own and Harrod's notions of neutral inventions while preparing the second edition of *Theory of Wages* he highlighted the fundamental differences in their respective conception which escaped most of their interpreters:

"My (Chapter VI *Theory of Wages*) discussion is, as I have now explained, purely a static comparison, in which the stock of capital (physical capital) is an independent variable; this applies to the invention part, as well as to the other part, of my discussion. Thus I entirely agree that my classification (like Pigou's) assumed the stock of capital to be fixed. I still believe that that approach is useful for some, but by no means for all, purposes. It is in any case a short-period theory, analogous to Marshall's short-period equilibrium.

²³ Robinson to Harrod, 13 May 1937; Keynes to Harrod, 28 March 1935; in this letter Keynes suggested that Harrod should read Hill (1933) and Gifford (1933), where this concept is also explained

²⁴ See for instance his discussion with Keynes on his use of 'ex ante' and 'ex post' (the relevant correspondence, which took place during Summer 1938, is printed in Keynes 1973, pp. 322 and 337). As to the notion of 'neutral' inventions, Joan Robinson complained that it was a pity that Harrod insisted in using the same terminology as Hicks, as the name was tagged to something else (Robinson to Harrod, 13 May 1937).

Your theory, as I now see it, is a long-period theory where (in equilibrium) the supply of capital (i.e. the stock of capital) is not an independent but a dependent variable, adjusting itself to the other data of the system, such as the rate of growth. In such a system a definition of "invention neutrality" such as mine is not possible; one has to have a definition of the same type as yours, into which the stock of capital does not explicitly enter. Basically this is because in your system it is the *same* equilibrium when capital has doubled and everything else has doubled, as it was before. The definition must therefore run in terms of things which are the same all along one equilibrium path, but differ from one equilibrium path to another" (Hicks to Harrod, 30 January 1963. See also Hicks 1963, pp. 348-50).

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The following abbreviations have been used: HP indicates the Harrod Papers, Chiba University of Commerce, Ichikawa, Japan; JMK the Keynes Papers, King's College, Cambridge; KHLN the Keynes and Harrod Letters and Memoranda, Tokyo University; LoN indicates the League of Nations Archives, Geneva; NKP the Kaldor Papers, King's College, Cambridge.

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