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The Cambridge–Cambridge controversy on the theory of capital: 50 years after*

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The paper points out that capital theory has always been a hotly debated subject, partly because the theoretical issues involved are very complex, and partly because rival ideologies and value systems directly affect the issues discussed. The focus is on the history, the main protagonists, and the relevant problems examined and argued about during the two Cambridges controversy on the theory of capital which was at its peak 50 years ago. Whereas one clear result of these debates is that neither Samuelson's surrogate production function nor Solow's rate-of-return concept could resurrect aggregate neoclassical theory, many other questions, such as the treatment of capital in temporary or intertemporal general equilibrium models or the empirical relevance of the reswitching phenomenon, are still discussed controversially.

Keywords: *Austrian theory of capital, capital theory, Cambridge controversy, reswitching, Sraffa, wage-profit curve, Wicksell effects*

JEL codes: *B25, B51, C67, D57, E22, O33*

Capital theory connects two major areas of economics: the theory of production and the theory of distribution. It has always been a hotly debated subject, partly because the issues involved are very complex, and partly because rival ideologies and value systems directly affect the issues discussed. Ideological causes or motives result from the fact that ‘capital’ possesses a double character in capitalist societies. On the one hand, it represents the total of physical instruments of production, that is, capital goods, which by nature are heterogeneous and cannot be aggregated in physical terms. On the other hand, ‘capital’ is considered as a homogeneous fund of value and source of income in the form of profits. In contrast to centrally planned economies, the legal institution of private property causes a close link between production and distribution in capitalism.

Analytical problems arise from the fact that the value of capital goods corresponding to each system of production, even with a constant technique, will change with income distribution in whatever unit they are measured. Current relative prices change when the rate of profits and correspondingly the real wage change (except in the two special cases of an equal capital–labour ratio in the production of the various commodities or of a zero rate of profits), so that the same physical capital represents different values whereas different stocks of capital goods can have the same value. Furthermore, only in long-run equilibrium will a given stock of capital goods have the same value, whether it be determined

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as the accumulated sum of past investment expenditures or as the present value of the sum of expected future net returns discounted at the ruling rate of profits.

Since Ricardo's investigation of the role of capital in the determination of relative prices, economic theory has been characterized by intensive controversies on capital theory in which almost all major economists were involved. At least three major controversies deserve to be mentioned. The first one broke out at the turn of the twentieth century and took place in three leading journals: *The Economic Journal* of the British Royal Economic Society, the Harvard-based *Quarterly Journal of Economics* and the Chicago-based *Journal of Political Economy*. The main protagonists were John Bates Clark, Eugen von Böhm-Bawerk, Irving Fisher and Frank A. Fetter.¹ The second one took place in the 1930s and intensified after Hayek had integrated elements of Böhm-Bawerk's theory of capital into his Austrian business cycle theory in the famous triangles of chapter 2 in *Prices and Production* (Hayek 1931), in which the focus is on the real phenomena constituting cyclical fluctuations. The debate centred on Böhm-Bawerk's notion of the 'average period of production' and culminated in discussions on the concertina effect, the Ricardo effect and the Ricardo–Hayek effect. Among major critics we find Frank Knight, Oskar Morgenstern, Jacob Marschak and Nicholas Kaldor. The debate animated Hayek to further pursue his idea of introducing the time factor into the theory of capital leading to his penetrating *The Pure Theory of Capital* (Hayek 1941).² There he finally gave up the concept of the average period of production as a useless tool which 'is not only unnecessary but is also highly misleading' (ibid.: 76). Steedman (1994: 23) concludes his modern critical assessment of Hayek's *Pure Theory of Capital* with the 'quite unambiguous statement; by 1941 Hayek had already provided a convincing dismissal of any attempt to employ the aggregate value of capital, or an average period of production as a datum in theoretical economic analysis'.

Nevertheless several of these problems around the meaning and measurement of capital as well as (dis-)equilibrium and time entered centre-stage again in the controversy which was at its peak when Geoff Harcourt (1969) wrote the widely read survey article, 'Some Cambridge controversies in the theory of capital', published for the American Economic Association 50 years ago which he elaborated into a book shortly afterwards.³ Joan Robinson's attack on the neoclassical production function as 'a powerful instrument of miseducation' (Robinson 1953/1954: 81) was a kind of prologue, but the controversy gained momentum only after Piero Sraffa's *Production of Commodities by Means of Commodities* (1960) had been published. The author made a seemingly modest claim when he gave his book the subtitle *Prelude to a Critique of Economic Theory*, but his

1. For an excellent survey of this debate, see Perlman (1991).

2. The book marked 'the end' of what is considered 'Hayek I' (the theoretician who analyses money, business cycles, capital and general equilibrium) at a time when 'Hayek II' (the social and economic philosopher) had already emerged.

3. Harcourt also co-authored with Avi Cohen a retrospective on the Cambridge capital theory controversies (Cohen/Harcourt 2003) and edited with Christopher Bliss and Avi Cohen a three-volume collection called *Capital Theory* (Bliss et al. 2005). However, the three editors agreed to disagree and wrote two separate introductions. Whereas Cohen and Harcourt are strong followers of the Cambridge UK position, Bliss is critical of these views as well as of the use of aggregate production functions. In his *Capital Theory and the Distribution of Income*, Bliss (1975) elaborated his own theory of capital as an extension of equilibrium theory in which he emphasizes the intertemporal aspect of production and consumption, drawing on Malinvaud's classic paper (1953). Although he explicitly does not follow the Austrian model, Bliss considers capital and time closely interlinked and recommends the reading of Hicks (1973) and von Weizsäcker (1971), who tried to rehabilitate the Austrian view (Bliss 1975: 6, n. 3).

intentions went far beyond this: to criticize neoclassical orthodoxy and its treatment of the quantity of capital in a positive-profit framework and to revive classical political economic thought. In the spirit of Ricardo, whose works and correspondence he had begun to edit in 1951, Sraffa showed how relative prices vary with changes in the rate of profits (wage rate).

This was well understood by the leading neoclassical theorists, among whom Paul A. Samuelson and Robert M. Solow at MIT in Cambridge, Massachusetts, took the lead against the challenge coming from the critics in Cambridge, UK.⁴ This controversy in the theory of capital, which intensified in the 1960s and slowly petered out around the mid 1970s, has become known as the *Cambridge–Cambridge controversy* or the *Two Cambridges controversy* because of the locations of the main protagonists. The controversy petered out without agreement on major issues, except that the results of the extremely aggregated version of neoclassical theory of the Clark–Solow parable cannot simply be transferred to a world with heterogeneous capital goods. Nevertheless, today, when this debate seems almost forgotten, many empirical investigations are still based on the Cobb–Douglas function as if no problems would be involved. The Cambridge–Cambridge controversy ended without agreement on the significance of many important results. The assessment of the opponents depended very much on the different criteria used to judge the outcome of the debate. The participants in the panel therefore have been asked to focus their contributions on the following questions/issues:

- What remains of reswitching, capital reversing and the critique of neoclassical theory?
- Is intertemporal general equilibrium from Malinvaud to Bliss and beyond a successful way out?
- Marx after Sraffa and Sraffa after Marx
- How much is Keynesian economics affected by the capital-theoretic critique generated in Cambridge, UK?⁵
- Horizontal (sectoral) versus vertical (dis-)integration of production structures: advantages and drawbacks
- Böhm-Bawerk and the Austrian theory of capital
- Hicks and neo-Austrian theory
- Production as a circular flow (Leontief/Sraffa/von Neumann)
- Fixed capital and joint production

With Heinz D. Kurz, Bertram Schefold and Carl Christian von Weizsäcker the panel comprised the three leading scholars on capital theory in the German language area then and now. All three of them soon gained an international reputation. Carl Christian von Weizsäcker (born 1938) became first known internationally with his 1961 Basel PhD thesis in which he showed that the optimal rate of interest (that is, the rate which maximizes consumption per capita over time) is equal to the rate of growth (Weizsäcker 1962). Some years after the construction of the basic neoclassical growth model by Solow (1956) this was a multiple discovery, independently made by von Weizsäcker, Edmund Phelps in the USA, Joan Robinson and James Meade in England, and Jacques Desrousseaux in France. Due to the work of Phelps this result has entered the economic literature as the ‘golden rule of

4. Due to Sraffa, Pierangelo Garegnani and Luigi Pasinetti as leading critics, Cambridge UK figures also as the ‘Anglo-Italian’ School in this capital controversy. See also the contributions in Eatwell et al. (1990).

5. See section 8 of the contribution of Kurz to this panel and Garegnani (1978/1979).

accumulation', $r = g$. As a research fellow of the German Research Foundation DFG he visited both Cambridges between 1962 and 1965. From 1965 to 1972 he was Professor at the University of Heidelberg, interrupted in 1968–1970 when he was Full Professor of Economics at MIT, where Robert Merton, Robert Shiller and Stanley Fischer were among his students. Among the joint papers he wrote with Samuelson and Solow during that period is an article with Samuelson which showed that the golden rule case or 'synchronized labour values' is the third special case (besides $r = 0$ and identical machine–labour ratios or equal organic compositions of capital in all sectors of the economy) in which Marx's labour theory of value is valid (Weizsäcker/Samuelson 1971). Weizsäcker's Heidelberg lecture notes *Steady State Capital Theory* (1971) are also a main outcome of this period. There he also thanks his former teacher Friedrich Lutz from whom he took capital theory as one of his favourite subjects (see Weizsäcker 1971: 3). Lutz had been the author of the introductory essay 'The essentials of capital theory' and co-editor of the proceedings of the famous conference on 'The theory of capital' held by the International Economic Association in Corfu in 1958 (Lutz/Hague 1961). The conference, at which Samuelson and Solow as well as Hicks, Kaldor et al. presented major papers, was also attended by Sraffa who in the debate pointed out a sharp distinction between two types of measurement: *measurement in theory* which required absolute precision, and *statistical measurement* which is only of an approximate nature. 'One therefore had to keep the definition of capital separate from the needs of statistical measurement, which were quite different. The work of J.B. Clark, Böhm-Bawerk and others was intended to produce pure definitions of capital, as required by their theories, not as a guide to actual measurement' (Sraffa in Lutz/Hague 1961: 306).

Stimulated by the conundrum of the 'savings glut' and before Larry Summers's revitalization of Alvin Hansen's secular stagnation hypothesis, Weizsäcker since 2010 has elaborated his lecture notes which culminated in the manuscript *Capital Theory of the Steady State* (Weizsäcker 2019).⁶ A main result is that the *golden rule* optimum ($r = g$) is characterized by the equation $D = Z - T$, provided that the government can borrow at the risk-free equilibrium rate of interest r ; where Z is the waiting period of the representative private household, T is Böhm-Bawerk's period of production in the modernized version of Hicks (1939), and D is the public debt, that is, net public debt divided by national consumption.

Bertram Schefold (born 1943) also became well known internationally with his PhD thesis *Mr. Sraffa on Joint Production* (Schefold 1971), in which he took up and elaborated the mathematically complex issues of fixed capital and joint production which Sraffa (1960) had addressed in part II of his classic work. After graduating in mathematics, theoretical physics and philosophy in his home town of Basel in 1967, Schefold had spent the years 1969 and 1970 in Cambridge, UK, where he came into close personal contact with Joan Robinson, Kaldor, Sraffa and Luigi Pasinetti, who was the second assessor of his PhD thesis, mainly written in Cambridge but presented to the University of Basel in 1971. There, almost a decade later, Schefold did not only share with von Weizsäcker the same university where they received the PhD degree, but with Gottfried Bombach also the same supervisor and intellectual mentor. Schefold returned to Cambridge in 1972–1973 as a supervisor at Trinity College, which was also Sraffa's college, and spent the subsequent year as a research associate at Harvard (and MIT) in the other Cambridge before in 1974 he was appointed Full Professor at the Goethe University in Frankfurt. One of his first activities there consisted of writing a long postscript (Schefold 1976) to the first West German edition of Sraffa's book *Warenproduktion mittels Waren*, in the translation as it had been published first in

6. Another outcome is the recent book on *Saving and Investment in the Twenty-First Century: The Great Divergence* (Weizsäcker/Krämer 2019).

East Berlin in 1967. During the following decades Schefold was recognized internationally as a leading expert on the problems of joint production and fixed capital, as is indicated by his collection of essays (Schefold 1989) which also contains an extended version of his Basel PhD thesis.

Born in a suburb of Munich in 1946, Heinz Kurz is the youngest of our three panelists. After receiving the diploma in economics at the University of Munich he moved to Kiel in late 1971. There Heinz, I and our PhD supervisor Albert Jeck soon formed a 'Sraffa study group', also investigating intensively the writings of Smith, Ricardo and Marx and the Cambridge controversies in the theory of capital which was still in full swing.⁷ In June 1975 he got his PhD with his thesis *On the Neo-Ricardian Theory of General Equilibrium of Production and Circulation* with the subtitle *Value and Distribution in Piero Sraffa's Production of Commodities by Means of Commodities* (Kurz 1977). The main aim of the book is to unravel the roots of Sraffa's work in classical economics and to show how much Sraffa had taken up, elaborated or modified the approaches and results of his important predecessors Smith, Ricardo and Marx. The author considers Sraffa's work as the culmination of the *objectivist value and price theory* and points out explicitly in his preface the invaluable help of Schefold's study *Mr. Sraffa on Joint Production* for the transformation of the verbal arguments into mathematical formulations.

From his Kiel PhD thesis there is a direct route to the *Theory of Production* in which Heinz Kurz and Neri Salvadori (1995) investigate the doctrinal history and mathematical analysis of the relationship between production, income distribution and relative prices in a competitive capitalist economy in long-period equilibrium. The book represents the *magnum opus*, that is, the culmination of Kurz's and Salvadori's scholarly work, on which Paul Samuelson states (on the back page of the book): 'I expect to wear out a copy every two years from extensive use'.

After the publication of his thesis, Kurz came into closer contact with Pierangelo Garegnani and, during his stay as a visiting fellow of Wolfson College in Cambridge, UK, in the academic year 1977–1978, also with Ian Steedman, author of the highly influential book *Marx After Sraffa* (Steedman 1977). After the death of Sraffa in 1983, Garegnani (1930–2011), who got his PhD from the University of Cambridge in 1959,⁸ became the literary executor of the works, documents and papers left by Sraffa to Trinity College, Cambridge, UK. Heinz Kurz's long cooperation with Garegnani on classical economics culminated in an invitation to him to become the general editor of Sraffa's unpublished papers and correspondence. While the long and winding process of publishing these with Cambridge University Press is still not finalized, with the endorsement of Sraffa's current literary executor John Eatwell, in 2016 the Wren Library began releasing important files from the Sraffa papers and made them available online. Heinz Kurz has in the meantime published *inter alia* a collection of essays on Sraffa's legacy in economics (Kurz 2000) and alone or together with Christian Gehrke and Neri Salvadori several articles on various aspects of Sraffa's preparatory work that led to his 1960 book; see, for example, Kurz (2012).

While Garegnani wrote his thesis, *A Problem in the Theory of Distribution from Ricardo to Wicksell*, at the University of Cambridge, he was in close contact with Sraffa and Maurice Dobb (who had helped Sraffa with the Ricardo edition); he defended it in Cambridge with Joan Robinson and Lionel Robbins as examiners. The thesis was published in Italian, but several of Garegnani's later English articles (1970; 1978/1979; 1984), covering an account of the theoretical core of the classical economists and Marx and a critique of neoclassical

7. For further details, see my essay 'Sraffa at Kiel' (Hagemann 2012).

8. His PhD thesis was later published, in Italian, as Garegnani (1960).

theory, derived from main ideas already included in his thesis. Garegnani spent the academic year 1961–1962 as a Rockefeller Foundation fellow at MIT, exactly at the time when Paul Samuelson took up the challenge by Robinson's attack against the neoclassical aggregate production function. Samuelson (1962) dedicated his article on the *surrogate production function* 'to Joan Robinson on the occasion of her memorable 1961 visit to MIT' (ibid.: 193). With his construction, Samuelson attempted to show that key results of the simplified Clark–Ramsey–Solow parable with only one homogeneous capital good ('jelly') would also hold in models with heterogeneous capital goods and constant-returns-to-scale technology. Thus he pointed out

that even in our discrete-activity fixed-coefficient model of heterogeneous physical capital goods, the factor prices (wage and interest rates) can still be given various long-run marginalist (i.e. partial derivative) interpretations. And all this without our ever having to pretend there is any quantitative aggregate of homogeneous 'capital' that itself truly produces anything. (Ibid.: 200)

Samuelson's result, however, depends on his simplifying assumption of equal machine–labour ratios in the two sectors of the economy for each technique in the book of blueprints. Interestingly, in the final note (on page 202) of the text, Samuelson thanks Garegnani 'for saving me from asserting the false conjecture that my extreme assumption of equi-proportional inputs in the consumption and machine trades could be lightened and still leave one with many of the surrogate propositions'. However, Samuelson's hope that Garegnani's demonstration – showing why the surrogate case based on the assumption of identical machine–labour ratios is so special – would eventually get published was not fulfilled until 1970. It should be added that the validity of Samuelson's surrogate production function does not only require equal physical proportions in all processes but also the special assumption of exponential depreciation of fixed capital (or depreciation by evaporation, or radioactive decay).

Meanwhile the Cambridge controversy had intensified particularly in the pages of *The Quarterly Journal of Economics*, where Samuelson's student Levhari had postulated the nonswitching theorem, that is, claimed to have shown that 'reswitching' was impossible. This led to a major symposium in 1966 in which Pasinetti, Garegnani et al. provided counter-examples which caused Samuelson and Levhari to concede that the nonswitching theorem is false. In his 'Summing up' of the debate, Samuelson (1966: 582) states that 'reswitching is a logical possibility in any technology, indecomposable or decomposable. Reswitching, whatever its empirical likelihood, does alert us to several vital possibilities'. In this phase the Cambridge controversy focused on reswitching and capital reversing because these phenomena challenge the traditional marginalist view in production (and consumption).

This brings us to a more systematic discussion of price and real Wicksell effects, an issue also addressed by our three panellists from various perspectives (see also Hagemann 1977: 206–227). The price Wicksell effect is associated with the relationship between the real wage rate w and the rate of profits r , which corresponds to a single technique α, β, \dots in the book of blueprints and is related to changes in the value of the capital–labour ratio k for alternative long-run equilibrium positions (where the rate of interest is equal to the rate of profits). In a world of heterogeneous commodities in general, the value of k depends on r as well as on the rate of growth g . Changes in the value of k are the outcome of two components: the price Wicksell effect and the composition effect; r , a variable of the price system, and g , a variable of the quantity system, are connected via the saving–investment behaviour. In a two-sector Hicks–Samuelson model it can easily be shown that a higher growth rate g increases the weight of the capital-goods-producing sector. Whether this composition effect strengthens or counteracts the price Wicksell

effect depends on the different machine–labour ratios in the two sectors and the saving function. In the special case of the golden rule $r = g$, the price effect and the composition effect exactly neutralize each other.⁹

In a stationary economy where the whole net output consists of consumption goods, the composition effect does not exist and the price effect can be isolated. For this reason, very often Wicksell effects are discussed under the assumption of a stationary state (see for example Harcourt 1972: 39–45). A *neutral price Wicksell effect* (or zero in von Weizsäcker's terminology) exists if the value of k does not change with r , as in the case of Samuelson's surrogate production function with equal machine–labour ratios where the w – r relation, the wage curve, is linear.

A *positive price Wicksell effect*, or neoclassical Wicksell effect in the language of Schefold, exists if a lower k is associated with a higher r . In that case the curve for a given technique is convex to the origin. A *negative price Wicksell effect* ('anti-neoclassical') exists if the value of k increases with r . The wage curve is concave to the origin.

A real Wicksell effect is associated with a change in the technique of production. It has been a traditional belief of marginalist theory, based on the principle of substitution, that a higher (lower) r is associated with the use of a more labour- (capital-) intensive technique, or in other words: if the wage rate w increases, capitalists choose a more 'capital'-intensive (less labour intensive) technique of production. Accordingly, a *positive real Wicksell effect*, or forward switch, exists if with a higher (lower) rate of profits a new technique with a lower (higher) value of capital per capita k is chosen.

A *negative real Wicksell effect*, backward switch or *capital reversing* exists if with a higher (lower) rate of profits a switch will be made to a technique with a higher (lower) value of capital per capita. A negative real Wicksell effect or capital reversing can even exist if both techniques α and β are characterized by convex wage curves (positive price Wicksell effects), that is, production in the consumption-good sector is more machine-intensive.

Reswitching implies the possibility that the same technique may be the most profitable of many contained in the book of blueprints at more than one rate of profits (or range of r) even though other techniques are more profitable in between. As a consequence, techniques or methods of production cannot be ordered monotonically with the rate of profits.

Parallel to the controversy between Samuelson and Garegnani ran the controversy between Solow and Pasinetti.¹⁰ Solow (1963; 1967) had defined his concept of the social rate of return on saving in reference to Irving Fisher solely in terms of changes in consumption streams: the perpetual gain in consumption is compared to the sacrifices in consumption during the transition period. Solow's approach must be understood as an alternative attempt to form a surrogate for the marginal productivity of capital in a world with heterogeneous capital goods at a time when the 'unobtrusive postulate' (Pasinetti 1969: 519), that is, that a fall in the rate of profit will lead to a technique with a higher capital intensity, was under vehement attack.¹¹ Some of the controversies arise from different assumptions of the underlying system of production and consumption. Whereas Solow based his theorem of the rate-of-return property of the rate of profit on the presupposition that all commodities serve equally well for production and consumption purposes, similar to the malleability of the only good 'jelly' in his basic growth model (Solow 1956), Pasinetti, to the contrary,

9. With only one consumption good (serving also as the numéraire) or a fixed basket of consumption goods, duality holds, that is, the c – g relationship is parametrically identical to the w – r relation.

10. For a more-detailed retrospective, see Hagemann (1997).

11. Solow's rate-of-return concept is based on the fundamental duality between the wage-profit and the consumption-growth relationship.

emphasized special costs of transitions even in switchpoints in the form of capital-goods wastages, sacrifices on consumption, and some technological unemployment, thereby undermining Solow's theorem. As Kurz points out in his contribution, for some leading neoclassical economists such as Samuelson and Burmeister, the possibility of a positive relationship between consumption per capita and the rate of interest was particularly intriguing.

A clear result of these debates is that neither Samuelson's surrogate production function nor Solow's rate-of-return concept could resurrect aggregate neoclassical capital theory. This is also elaborated in the contributions by Kurz and Schefold. However, despite their common Sraffian background, the two authors seriously disagree regarding the empirical relevance. Schefold, although agreeing that price Wicksell effects, including negative or anti-neoclassical ones, are ubiquitous, is emphasizing new developments in capital theory which demonstrate that capital reversing and reswitching have turned out to be empirically rare. Since his cooperation with Han in 2006, Schefold has published several papers in which he investigates the wage–profit frontier as the envelope of thousands of wage–profit curves constructed from detailed input–output tables with 30 sectors or more (see sections 4 and 5 of Schefold's contribution in this issue). This leads him to the conclusion 'that the Cambridge critique has been transformed considerably because reswitching, which once constituted the main objection against neoclassical theory, has turned out to be irrelevant for large systems' (Schefold 2020: 237). Furthermore, and surprisingly, with his emphasis on the quasi-linearity of empirical wage curves, Schefold comes close to justifying both Marx's transformation of values into prices and Samuelson's surrogate production function (section 5).

This is an argument that Kurz is seriously unable to accept, and he not only refers to leading neoclassical economists such as Mas-Colell, who had pointed out that the relationship between k and r can have almost any shape whatsoever, but particularly in section 6 elaborates a detailed argument concerning the methodological problems involved in bridging the gap from a purely theoretical model to empirical input–output tables (capital matrix B , time delay, new goods and sectors coming up due to innovation, and old ones which are shrinking or disappearing). Furthermore, the coefficients of actual input–output tables are not technological coefficients as they would be in a Sraffian model, but are derived from value measures.¹²

The differences between Kurz and Schefold echo somewhat Sraffa's sharp distinction at the 1958 Corfu conference between theoretical and statistical measurement. A sharp distinction should also be made in that context between *choice* of technique within an existing technology or book of blueprints at a certain point in time and technological *change* over time. Joan Robinson, who was co-responsible for kicking off the capital controversy with her 1953/1954 contribution and her emphasis on capital reversing (the 'Ruth Cohen curiozum'), was probably the first on the Cambridge UK side to point out 'The unimportance of reswitching' (Robinson 1975). The state of technical knowledge changes over time, and technical progress shifts the wage–profit frontier in the northeastern direction. Although due to different technical coefficients various wage–profit curves (frontiers) are imaginable, the higher the rate of technical progress and the longer the space of time, the lower the possibility of reswitching becomes.

12. Therefore Felipe/McCombie (2013:42) claim that the input-output table is a snapshot measured in value terms, using price deflators. Thus, they suffer from the same problem as regression studies on neoclassical production functions where one cannot move smoothly from output and capital measured in physical magnitudes to one where they are measured in value terms.

Carl Christian von Weizsäcker is deploring in his contribution that '[t]he Cambridge–Cambridge controversy took little account of the Austrian tradition in capital theory' (Weizsäcker 2020: 208) and that his own book (Weizsäcker 1971) was an exception.¹³ He focuses on Böhm-Bawerk's concept of the period of production in the modernized version as elaborated by Hicks (1939) in the parts on the foundations and working of the dynamic system of *Value and Capital*. This book was the main reason that in 1972 Hicks (the first British economist to be bestowed the prize) was awarded the Bank of Sweden Prize in Economic Sciences in Memory of Alfred Nobel, together with Kenneth Arrow, 'for their pioneering contributions to general equilibrium theory and welfare theory'.

In the famous chapter 6, 'Distribution and economic progress', of his preceding *The Theory of Wages* Hicks (1932) had pioneered the new concept of the 'elasticity of substitution' (referred to also by von Weizsäcker) which became central for the neoclassical argument that a rise (fall) in the $w-r$ ratio would cause an increase (decrease) in the capital–labour ratio k , or, when integrating technical progress, leads to innovating more capital- (labour-) intensive techniques. In the Austrian model roundaboutness is a measure of capital intensity, and the equivalent to a rise (fall) of k is the lengthening (shortening) of the period of production. Accordingly, Hicks (1939: 220) states that '[a] fall in the rate of interest lengthens the average period'. However, this statement is made under strict premises because Hicks is aware of a problem:

The average period of a stream ... is a satisfactory index of the time-shape of the stream only when it is calculated at a *given* rate of interest. The same stream will have a whole series of different average periods, arrived at by using different rates of interest in the calculation. If the average period changes, without the rate of interest having changed, it must indicate a change in the stream; but if it changes, when the rate of interest changes, this need not indicate any change in the stream at all. (Ibid.: 219–220).

Hicks is pointing out an error in Böhm-Bawerk, whom he criticizes for generalizing an argument which holds only in his special case of a point input–point output model in which the average period of production must equal the actual period, that is, the time until the production process is completed.

Hicks kept a deep interest in capital theory throughout his life. 'Capital is a very large subject, with many aspects; wherever one starts, it is hard to bring more than a few of them into view', Hicks (1973: v) writes in the preface to the last volume of his famous trilogy *Value and Capital* (Hicks 1939), *Capital and Growth* (Hicks 1965) and *Capital and Time: A Neo-Austrian Theory* (Hicks 1973). The decisive Austrian elements in Hicks's 'neo-Austrian' theory are a focus on the time structure of the production process and the special treatment of capital goods as intermediate products in a vertical model.

Capital goods are a medium for sequential production. By dealing explicitly with fixed capital goods Hicks (1973), in contrast to Böhm-Bawerk and Hayek, considers production processes to be of the flow–input–flow–output type. He elaborated his neo-Austrian theory mainly to allow for a modern investigation of Ricardo's machinery effect. The relevance of the time dimension is particularly important in the taking-up or diffusion process of a new technology.

Hicks attempted to overcome some of the deficiencies of Böhm-Bawerk's theory of capital and felt the need to abandon the concept of the average period of production and

13. It should be added that Malte Faber, his successor at the University of Heidelberg, also made many contributions to modern Austrian capital theory in the 1970s and 1980s.

of the exclusive focus on intermediate capital goods.¹⁴ As Hicks (1973: 8–9) points out, his generalization of the process of production from an output at a point in time to a stream of outputs over time implies a collapse of the whole notion of roundaboutness. However, in Hicks’s integration of fixed capital goods in the analysis in the very first stage of the construction process of a machine only labour inputs are used, that is, there are no basic products in the neo-Austrian model and therefore also no maximum rate of profits. Solow’s former PhD student, Edwin Burmeister (1974), has provided an excellent synthesis of Hicks’s neo-Austrian model with the more general von Neumann–Sraffa approach in which capital goods enter already at the very first stage. On the basis of such a von Neumann–Sraffa treatment of fixed capital goods, Hagemann/Kurz (1976) have shown that Hicks’s fundamental theorem, ‘that a fall in the rate of interest will raise the capital value curve of any process – will raise it throughout – while a rise in the rate of interest will lower it’ (Hicks 1973: 19), is without foundation. Likewise, the statement that, with an optimal truncation of production processes (that is, potential termination before the end of its physical lifetime) the economic lifetime of a fixed capital good is inversely related to the rate of interest, is not valid. The possibility of the return of the same truncation period, a phenomenon closely linked to reswitching of techniques, exists even within a neo-Austrian model, which is a special case of the von Neumann–Sraffa model. Burmeister (2009: 50–53) shows that the following five Austrian properties:

- the degree of roundaboutness increases as the interest rate falls,
- per capita consumption rises as the interest rate falls,
- capital values rise as the interest rate falls,
- the economic lifetime of a machine increases with decreases in the interest rate, and
- the optimal durations for production processes in use increase with decreases in the interest rate,

hold in special cases only.

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14. Interestingly, Hicks (1939: 117) had already stated that ‘Wicksell was a Walrasian on Value, but an Austrian on Capital’, and considered the capital theory in the first volume of Wicksell’s *Lectures* as ‘more refined’ than that of Böhm-Bawerk. For a more detailed comparison of Hicks’s neo-Austrian theory and Böhm-Bawerk’s Austrian theory of capital, see Gehrke/Kurz (2009).

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