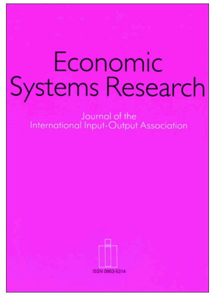

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Alfred Kähler's *Die Theorie der Arbeiterfreisetzung durch die Maschine*: an Early Contribution to the Analysis of the Impact of Automation on Workers

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ABSTRACT *This paper provides a critical assessment of Alfred Kähler's pioneering contribution to the analysis of the impact of automation on workers in his 1932 dissertation thesis* Die Theorie der Arbeiterfreisetzung durch die Maschine *(The theory of the displacement of the worker by the machine). Kähler's analysis is shown to be an elaboration on Ricardo's and Marx's approach to the analysis of the labour displacement and compensation process. It is also shown that the arithmetical 'circulation schemes' developed by Kähler can be interpreted as an early formulation of a closed (static) input–output model. In addition, the paper also examines Kähler's rudimentary discussion of the associated price model and of the choice of technique problem.*

1. Introduction

This essay provides a critical assessment of Alfred Kähler's treatise *Die Theorie der Arbeiterfreisetzung durch die Maschine* (The theory of the displacement of the worker by the machine), which was submitted as a doctoral dissertation at the University of Kiel in 1932 and was published (in German) in 1933 (Kähler, 1933). Kähler's thesis, the research on which was conducted in the late 1920s and early 1930s under Adolph Lowe's guidance at the Institute of World Economics in Kiel, contains the first systematic attempt to provide a theoretical analysis of the problem of technological unemployment on the basis of a multisectoral model of the economy. As will be shown in detail below, the arithmetical 'total circulation schemes' (*Gesamtumschlagsschemata*) developed by Kähler can be interpreted as an early formulation of a closed (static) input–output model. In addition, Kähler also provided a rudimentary discussion of the associated price model and of the problem of the choice of technique.[1]

The paper is organized as follows. Section 2 offers a short biographical sketch. Section 3 contains a summary of the first, 'critical' part of Kähler's treatise, in which he reconstructed the treatment of the machinery problem in the works of

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the classical economists. In the second, 'positive' part of his treatise, Kähler then used his findings in order to develop his own model of the economic circular flow and to study, in a coherent multisectoral framework, the problem of labour displacement and compensation by machinery. This part of Kähler's treatise is examined in detail in Section 4 of this paper. Section 5 contains a brief comparison of Kähler's model with analytical frameworks that have been adopted in some recent input–output studies on the problem of technological unemployment, including the model developed by Leontief & Duchin (1986). Section 6 offers a concluding assessment.

2. A Biographical Sketch

Alfred Kähler was born in Lübeck on 8 May 1900. He studied law and economics at the Hochschule für Politik in Berlin and at the University of Kiel from 1924 to 1927. He then obtained the post of the director of an adult education centre in Harriesleefeld (near the Danish border), which he held from 1928 to 1933. During this period he also participated in Adolph Lowe's seminars on economic theory at the Institute of World Economics in Kiel and conducted the research on his doctoral dissertation, which he submitted in 1932 at the University of Kiel. In 1934 he was forced to emigrate from Nazi Germany because of his political activities. He found refuge at the New School for Social Research in New York, where he became a Professor of Economics at the Graduate Faculty for Social and Political Research. Alfred Kähler officially retired from his professorship in 1966, but continued to teach classes as a Professor emeritus until 1974. He died on 12 September 1981 in Little Rock, Arkansas.[2]

While he worked on his thesis Alfred Kähler closely collaborated with, and was strongly influenced by, Adolph Lowe, Hans Neisser and Fritz Burchardt. Whether or not he was also in contact with Wassily Leontief, who stayed at the Institute of World Economics in Kiel for several months in 1927–28 and, again, in 1930–31, is not clear. In his treatise of 1933, Kähler, at any rate, made no reference to Wassily Leontief's seminal dissertation thesis, which was (partly) published in 1928 as 'Die Wirtschaft als Kreislauf' (Leontief, 1928).[3]

3. Kähler's Reconstruction of the Classical Theory of Labour Displacement and Compensation and his Elaboration of a 'Total Circulation Scheme'

In the first part of his treatise, Kähler discussed the major contributions to the long-standing controversy on the impact of machinery on employment. He emphasized that this controversy really focuses on the question of the precise conditions for the compensation of technological unemployment, as the emergence of technological unemployment in the short run is not disputed by advocates of the so-called 'compensation theory', nor is the possibility of the eventual re-employment of the originally displaced workers denied by the so-called 'displacement theorists'. The controversial issue is, rather, how fast, and under what conditions, a compensation of technological unemployment can take place. Kähler stressed that the classical political economists, and in particular Ricardo and Marx, saw the major precondition for a successful compensation in the sufficient formation of additional capital; that is, in the steady re-investment of the technological (extra-)profits that emerge from the introduction of cost-reducing production methods. Kähler made clear that his own study was meant to be an elaboration on the classical approach to the machinery problem and, in particular, on the contributions of Ricardo and Marx. In accordance with the classical political economists, he envisaged 'the capitalistic process as a race between displacement of labor through technological progress and reabsorption of labor through accumulation' (Neisser, 1942, p. 70).

While economists like Sismondi and Malthus had focused attention on the possibility of a lack of total purchasing power, and thus in total effective demand, as a consequence of the introduction of machinery, Ricardo in his famous chapter 'On machinery' had denied the possibility of 'general gluts' and had instead introduced the capital shortage dimension of the compensation problem.[4] Kähler stressed that his own contribution was meant to be an elaboration on Ricardo's approach, and that he would take over two important elements from the latter's analysis. First, he agreed with Ricardo's argument (against Sismondi) that the problem of technological unemployment is not primarily caused by an insufficient *demand* for commodities but rather by an insufficient *supply* of productive capital. Secondly, he also endorsed Ricardo's argument that the dominant form of technical progress that is most likely to cause large-scale labour displacement consists of the 'conversion of circulating capital into fixed capital'. He criticized Ricardo, however, for having based his analysis on wage-fund reasoning, and maintained that the main obstacle for the re-employment of the displaced workers is not an insufficient wage fund, but rather an insufficient stock of complementary fixed capital.

The same criticism of Ricardo's argument had already been raised by Marx.[5] However, in Kähler's view, Marx also had not succeeded in developing a satisfactory analysis of the labour displacement and compensation process (Kähler, 1933, p. 47). His main criticism of Marx's contribution to the analysis of technological unemployment is closely related to his idea (which he had taken over from Ricardo) that the displacement of workers by machinery is primarily caused by the 'lengthening of the turnover period of capital' which is associated with the conversion of circulating capital into fixed capital. In Kähler's view, Marx had failed to take this phenomenon properly into account, because his reproduction schemes only depicted those parts of the productive capital that are annually used up. Kähler argued that a proper analysis of the displacement and compensation process must be based on a 'total circulation scheme' which, in addition, also includes the sectoral *stocks* of productive capital.

3.1 Kähler's 'Total Circulation Schemes'

Before we can enter into a discussion of Kähler's 'positive analysis' of the impact of the introduction of machinery on the workers, we must first note some salient features of the so-called 'total circulation schemes' on which this analysis was based. In elaborating these schemes, Kähler made extensive use of a study by Fritz Burchardt (1931–32) which contained a critical assessment of the models of the circular flow developed by Böhm-Bawerk and Marx. Like Burchardt, Kähler criticized the Austrian production model of Böhm-Bawerk for its neglect of the circular relations of production. By assuming that only original inputs like labour and land are required at the first stage of the (uni-directional) Austrian production process, Böhm-Bawerk's scheme omitted an important feature of modern industrial systems, namely the physical self-reproduction of certain fixed capital goods (the 'production of machines by means of machines'). On the other hand, Marx's reproduction schemes, while giving proper recognition to the circularity relations in production, were also found wanting because of their neglect of the sectoral capital stocks.

In setting up his own scheme, Kähler started from a description of the 'cost composition' of the different commodities, that is, he started from a given system of production.[6] He stressed that 'the technique is of course not chosen at random, it will primarily be determined by considerations of profitability' (Kähler, 1933, p. 84). But at this stage of the analysis the problem of the choice of technique is set aside. The methods of production in use are taken to be known, and to consist of a set of (single production) processes with constant returns to scale—or, as Kähler put it:

> The relative cost composition in the production of coal is the same *as long as the technique remains the same*. A change in the total volume of coal production would have *no influence* on this cost composition. (Kähler, 1933, p. 84; emphases added)[7]

Apart from the 'cost composition' of the different commodities, Kähler also took as given the 'composition of consumption'; that is, he assumed that the proportions in which the commodities are demanded are known. Kähler indeed conceived of the consumption activities of the workers as 'the production of labour power by means of commodities and labour power'. In Kähler's scheme all commodities (including the commodity 'labour power') are assumed to be produced by using some produced means of production as inputs. The production (and consumption) of commodities is thus seen as a circular process:

> Let us begin, then, with the elaboration of our model of the circular flow, which has to show the production as well as the use of the different goods. The main users are of course the final consumers. But it would be wrong to suppose that they alone determine the size of the productions. The total volume of coal production, for instance, depends on the use of coal in the machinery industry as much as on the use of the final consumers. . . . But the use of coal in the machinery industry depends, inter alia, on the total volume of machinery production, which itself is codetermined by the amount of machines that are used in the mining industry. *The determination of the size of one sector thus always presupposes the knowledge of the size of the other productions*—which, however, can only be specified once the size of the first sector has been determined. (Kähler, 1933, pp. 83–84)

However, as Kähler correctly noted, the above assumptions suffice to determine all the quantity relations (except for a scale factor):

> The *absolute* numbers can only be determined if an absolute amount is specified for at least one of the productions. The *relative* size of the productions, however, can be determined without difficulty from a *general system of equations*. The resulting proportions are those that will have to hold in the economy under consideration, even if it grows. These proportions will indeed only change if there are shifts in human consumption, or if, because of technical changes, the input requirements of the means of production change. (Kähler, 1933, p. 87; emphases added)

Even if he conducted his analysis only in terms of simple arithmetical examples, Kähler was thus aware of the fact that, given the methods of production in use and the proportions in which the commodities are demanded, it was always possible to calculate the proportions of the associated 'total circulation scheme' from a *general system of equations*.

4. Kähler's Multi-sectoral Analysis of the Displacement and Compensation Process

Kähler's 'positive' investigation of the displacement and compensation process opened with a comprehensive classification scheme of different forms of technical progress that distinguishes between 27 types of technical progress, three of which were then analysed in more detail. The following discussion will be confined to a summary of Kähler's analysis of the third (and, in his view, practically most relevant) type of technical progress: the introduction of a new, labour-saving method that is associated with a 'lengthening of the turnover period of capital'.[8] For this case Kähler attempted to provide a systematic analysis of the labour displacement and compensation process by means of four different input–output tables, which were meant to depict the economic system in four successive 'phases' of the transition from an 'old' to a 'new' technique.

(i) Kähler's first table (Scheme I) describes the circular flow relations of the economic system in the initial situation, before the introduction of new machinery, at t_0. The system is supposed to be in a stationary equilibrium with zero profits; there is no (net) saving and no (net) investment.

(ii) The next table (Scheme II) is meant to capture the phase of the labour displacement. It depicts the (hypothetical) situation of the economic system at t_1, when a part of the original labour force has been displaced because a new, labour-saving method was introduced in some particular industry. The introduction of new machinery is associated with technological unemployment and, at the same time, with the emergence of technological extra-profits which provide a potential source for capital accumulation.

(iii) In the next step Kähler turns to the compensation phase, in which a successive re-employment of the originally displaced workers is supposed to take place because the technological extra-profits are steadily saved and invested. Scheme III shows the state of the economic system at the end of this accumulation phase, that is, at t_2, when the original labour force is again fully employed.

(iv) In the final step of the analysis Kähler then investigated the consequences of the redistribution of the productivity gains that are associated with the new technique. This redistribution of the productivity gains from the recipients of extra-profits to the recipients of wages is associated with the establishment of a new system of relative prices and a new structure of final demand. The corresponding stationary flow equilibrium of the economic system at t_3 is depicted in Scheme IV.

In the following, Kähler's (quasi-dynamic) analysis of the displacement and compensation process by means of a succession of arithmetical input–output tables will be examined in somewhat greater detail.

(i) Initial situation. In order to depict the economic system in the initial situation, Kähler used a highly stylized arithmetical 'total circulation scheme', which comprised four industries (Coal & Iron, Machines, Buildings & Construction, Agriculture) and a 'household sector' (Labour). As opposed to modern input–output

tables, Kähler's scheme depicted not only the interindustry flows but, in addition, also the associated sectoral capital stocks (see Scheme I). The figures in Kähler's table refer to both quantity and value magnitudes, since the system is normalized in such a way that all prices are equal to one. Labour, or rather the commodity 'labour power', is treated like a produced means of production: similar to all the other commodities, the table shows the annual sectoral flows and stocks of commodity inputs that are required in order to (re-)produce the commodity 'labour power'.

The flow magnitudes in Scheme I are derived from another table in which Kähler depicted the 'cost composition of production'. In this table the shares of the various inputs in total costs are calculated by setting the 'sum of the cost components' equal to 10.[9]

It is easily recognized that Kähler's total circulation scheme can be interpreted as a closed, static Leontief system. From Scheme I (and Ia) we can immediately calculate the following matrix of the production (and consumption) coefficients:

$$\mathbf{A} = \begin{pmatrix} 0.2 & 0.4 & 0.1 & 0.1 & 0.1 \\ 0.1 & 0.1 & 0.1 & 0.1 & 0.2 \\ 0.1 & 0.1 & 0 & 0.2 & 0.2 \\ 0.1 & 0 & 0.1 & 0.1 & 0.5 \\ 0.5 & 0.4 & 0.7 & 0.5 & 0 \end{pmatrix}$$

which consists of the usual matrix of interindustry production coefficients, $\tilde{\mathbf{A}}$, of the column vector $\mathbf{c}$, and of the row vector $\mathbf{1}^{\mathrm{T}}$, that is,

$$\mathbf{A} = \begin{pmatrix} \tilde{\mathbf{A}} & \mathbf{c} \\ \mathbf{1}^{\mathrm{T}} & 0 \end{pmatrix}.$$

Kähler's arithmetical table fulfils the conditions $(\mathbf{A} - \mathbf{I})\mathbf{x} = \mathbf{0}$ and $\mathbf{p}^{\mathrm{T}}(\mathbf{A} - \mathbf{I}) = \mathbf{0}^{\mathrm{T}}$, with $\mathbf{p}^{\mathrm{T}} = (\tilde{\mathbf{p}}\mathbf{I}(\tilde{\mathbf{p}}w)w)^{\mathrm{T}}$. Adopting the normalization $w = \tilde{\mathbf{p}}^{\mathrm{T}}\mathbf{c} = 1$ and $\mathbf{1}^{\mathrm{T}}\mathbf{x} = 1000$, prices and quantities are determined as $\mathbf{p}^{\mathrm{T}} = (1, 1, 1, 1, 1)$ and $\mathbf{x}^{\mathrm{T}} = (454, 391, 415, 652, 1000)$.

It should be stressed that Kähler's Scheme shows not only the annual flows but also the necessary sectoral stocks of the means of production (and of the means of consumption). These stocks consist, on the one hand, of inventory stocks of raw materials and semi-finished products ('working capital') and, on the other hand, of stocks of permanent means of production ('fixed capital'). These inventory and fixed capital stocks are lumped together in a single figure for each sector:

> If the machine industry, for instance, uses 10,9 units of coal per annum, it will of course not be necessary for this industry to hold a 'stock of coal capital' of the same amount, for at each moment it clearly needs to have only some fraction of the total annual use of coal in the inventory. But a certain stock of coal, part of which is continuously used up and replenished, will nevertheless have to be held in this industry. The average stock of coal will then constitute the necessary capital stock which underlies the use processes. The same applies also with regard to the relation between the use and the stock of machine tools. In order to continuously use up 16,4 units of machines per annum, one will again need to hold a certain

Scheme I (Initial scheme)

	Flows and Stocks in the production of										
	Coal and iron		Machines		Buildings		Agriculture		Labour		
Inputs	Flow	Stock	Flow	Stock	Flow	Stock	Flow	Stock	Flow	Stock	Total flow
Coal and iron	90.8	6	156.4	26	41.5	30	65.2	16	100	30	454
Machines	45.4	225	39.1	195	41.5	203	65.2	240	200	200	391
Buildings	45.4	360	39.1	390	0	0	130.4	800	200	2000	415
Agriculture	45.4	5	0	0	41.5	30	65.2	70	500	10	652
Labour	227	25	156.4	30	290.5	210	326	250			1000
Total production	454	621	391	641	415	475	652	1376	1000	2240	

Total stock of productive capital = 3113, Total wages = 1000, Productive capital : Total wages = 3.11.

Scheme Ia

	Composition of the costs in the production of					
		Machines				
Inputs	Coal and Iron	Old	New	Buildings	Agriculture	Labour (Profits)
Coal & Iron	2	4	6	1	1	1
Machines	1	1	2	1	1	2
Buildings	1	1	1	0	2	2
Agriculture	1	0	0	1	1	5
Labour	5	4	2	7	5	
(Profits)			1			
Sum of the cost components	10	10	12	10	10	10

> stock of machines, which in this case however will have to be larger than the amount that is annually used up. (Kähler, 1933, p. 93)

If we denote the matrix of the stocks of capital per unit of output with **K**, the total stocks of the different means of production (and of the means of consumption) in Kähler's Table I are given by $\mathbf{k} = \mathbf{Kx}$, where

$$\mathbf{K} = \begin{pmatrix} 0.013 & 0.066 & 0.072 & 0.024 & 0.03 \\ 0.5 & 0.5 & 0.5 & 0.368 & 0.2 \\ 0.8 & 1 & 0 & 1.23 & 2 \\ 0.01 & 0 & 0.07 & 0.1 & 0.01 \\ 0.06 & 0.08 & 0.5 & 0.38 & 0 \end{pmatrix}$$

(ii) Phase of labour displacement. Starting from Scheme I, Kähler next sought to ascertain the amount of labour that is displaced when a new method of production is introduced in the machine-producing industry. He accordingly assumed that there is a change in the 'cost composition' of the machinery industry (see columns two and three of Scheme Ia):

> While in our initial scheme ... we assumed that four value units of labour were combined with one value unit of buildings, one value unit of machinery and four value units of coal & iron in the production of machines, we now assume that two units of labour are combined with one unit of buildings, two units of machinery and six value units of coal & iron.... Since we calculate the units at the old cost prices, this change in the value composition is identical with a change in the composition of the use values. (Kähler, 1933, pp. 112–3)

Columns 2 and 3 of Scheme Ia thus show the change in the *physical* input requirements per unit of output. In interpreting the third column of this table it must be kept in mind that Kähler chose to describe the new production method by altering the 'total sum of the cost components' in the machinery industry (from 10 to 12), in order to take account of the increase in productivity that is associated with the new method:

> After the introduction of technical progress in the production of machines it must be possible, since the quantity units and the value units had before been set equal to one another, that a given amount of value units can produce a larger amount of quantity units. The amounts of the input flows are to be reckoned at their old values, at which they must also be purchased. We assume in our example that the output (in quantity terms) exceeds the former amount by 1/11. Formerly, an input of 11 units in value terms results in a production of 11 units in quantity terms; now, with the new technique, it is possible to produce with the same total costs 12 of the former units. In order to simplify the further analysis we shall assume that in spite of the cost reduction the value of the machines remains unchanged, so that 1/12 of the product's value emerges as profit. (Kähler, 1933, p. 113)

The new 'cost composition' of the machinery industry immediately gives the new production coefficients, because the 'input costs' are still calculated at the former prices (which were all equal to one): the amounts of inputs per unit of output in the machinery industry thus amount to 6/12 units of coal & iron, 2/12 units of machinery, 1/12 units of buildings, and 2/12 units of labour. In addition, a further 'cost element', amounting to 1/12 of the 'construction costs' of a machine, is made up of (extra) profits.[10] A corresponding change of the second column gives the 'new' matrix of the production and consumption coefficients

$$\hat{\mathbf{A}} = \begin{pmatrix} 0.2 & 0.5 & 0.1 & 0.1 & 0.1 \\ 0.1 & 0.17 & 0.1 & 0.1 & 0.2 \\ 0.1 & 0.08 & 0 & 0.2 & 0.2 \\ 0.1 & 0 & 0.1 & 0.1 & 0.5 \\ 0.5 & 0.25 & 0.7 & 0.5 & 0 \end{pmatrix}$$

in which the element $\hat{a}_{52}$ depicts the 'input of labour *plus technological extra-profit* per unit of output' in the machinery industry.[11] With the normalization $\hat{\mathbf{l}}^{\mathrm{T}}\mathbf{x} = 1000$ (where $\hat{\mathbf{l}}^{\mathrm{T}}$ is the fifth row of the matrix $\hat{\mathbf{A}}$), and taking into account that $\mathbf{x}^{\mathrm{T}}(\hat{\mathbf{A}} - \mathbf{I}) = \mathbf{0}^{\mathrm{T}}$, the numerical values of the flow magnitudes in Kähler's Scheme III are determined.

Starting from Scheme III, Kähler next calculated the (hypothetical) amount of labour that is displaced by the introduction of the new technique. The fundamental assumption for this calculation is that the new production method that was introduced in the machinery industry is associated with 'a lengthening in the turnover period of the capital that is employed in this industry':

> As regards the turnover period of capital, we shall assume that the durability of the buildings as well as the necessary amounts of the stocks of coal & iron remain the same, relative to the amounts of the flows. The new machines, however, are supposed to have twice the life-time of the old ones. Thus, in order to turn over the same amount of machines (in value terms) as before the capital stock must be twice as large. (Kähler, 1933, p. 113)

The lengthening (doubling) of the turnover period of the capital stock in the machinery industry is of crucial importance for Kähler's calculation of the (hypothetical) labour displacement effect, because the latter is based on the assumption that immediately after the introduction of the new method the same total amount of capital (in value terms) is available as before:

> The initial *scheme* I comprised ... 3113 capital units. This amount of capital must also suffice for the new technique, at least in the beginning.... The following circular flow calculation (*scheme* II) shows the associated numerical values, and it is only into this structure with these proportions of the numerical values that the economic circular flow can be transformed by the technical progress. (Kähler, 1933, p. 114)

In Scheme II, all the flow and stock magnitudes of Scheme III have been reduced proportionally, so that the value of the total capital stock employed in the economic system as a whole equals the initially available amount of 3113 units. The result of this calculation is a (hypothetical) labour displacement of 199 labour units. This displacement of labour is caused by a lack of complementary capital: with the new method and the same total stock of productive capital (in value terms) the flow of

Scheme III (= final scheme with a sufficiently large capital stock)

Inputs	Coal and iron		Machines		Buildings		Agriculture		Labour		Profit		
	Flows and Stocks in the production of												
	Flow	Stock	Flow	Stock	Flow	Stock	Flow	Stock	Flow	Stock	Flow	Stock	Total flow
Coal and iron	110.3	7.3	225.1	37.4	43.7	31.5	68.6	16.9	100	30	3.7	1.2	551
Machines	55.1	273.4	75	750	43.7	213.8	68.6	252.8	200	200	7.5	7.5	450
Buildings	55.1	437.5	37.5	375	0	0	137.2	842.5	200	2000	7.5	75	437
Agriculture	55.1	6.3	0	0	43.7	31.5	68.6	73.7	500	10	18.7	0	686
Labour	275.7	30.5	75	14.4	306.1	221.2	343.1	263.1					1000
Profit			37.5	7.2									37.5
Total production	551	755	450	1184	437	498	686	1449	1000	2240	37.5	83	

Total stock of productive capital = 3886, Total wages = 1000, Productive capital : Total wages = 3.88.

Scheme II (= scheme III, reduced to the initial capital stock)

Inputs	Coal and iron		Machines		Buildings		Agriculture		Labour		Profit		
	Flows and Stocks in the production of												
	Flow	Stock	Flow	Stock	Flow	Stock	Flow	Stock	Flow	Stock	Flow	Stock	Total flow
Coal and iron	88.2	5.8	180.3	30	35	25.2	55	13.5	80	24	3	0.9	441
Machines	44.1	218.6	60	600	35	173	55	202.5	160.2	160	6	6	360
Buildings	44.1	350.3	30	300			110	674.1	160.2	1600	6	60	350
Agriculture	44.1	5			35	25.8	55	59.1	400.6	8	15	0.3	550
Labour	220.9	24.3	60	11.5	245.3	177.4	275	210.8					801
Profit			30	5.7									30
Total production	441	604	360	948	350	401	550	1160	801	1792	30	67	

Total stock of productive capital = 3113, Total wages = 801, Productive capital : Total wages = 3.88.

capital that can annually be 'turned over' must be smaller, and therefore only a smaller number of workers than before can be equipped with complementary fixed and working capital.

(iii) Compensation phase. According to Kähler, Scheme III can be interpreted as depicting the situation at the end of the compensation phase, during which the total stock of productive capital is gradually increased by the continuous investment of the technological (extra) profits, which emerge as long as the former prices and wages prevail. Kähler assumed that the entire amount of the annually accruing extra-profits would be used for capital accumulation. With annual profits totalling 30.5 units, and an average capital intensity of 3.88, this implies that 'after one year employment opportunities for 30.5 : 3.88 = 7.75 labour units will have been newly created. But additional employment opportunities are required for 199 labour units, so that ... we arrive at a compensation period of roughly 25 years' (Kähler, 1933, p. 122).[12] Scheme III depicts the economic system at the end of this compensation phase, when the accumulated capital is sufficient to employ again the original 1000 labour units.

Comparing Schemes II and III, it is easily recognized that Kähler has simply supposed a proportionate growth of all sectors during the accumulation phase, until the total stock of productive capital is sufficient for the employment of the original 1000 labour units. However, it would clearly be more sensible to assume an unsteady growth of the different sectors, because the extra-profits that can be reaped in the machine-producing industry provide an incentive for the investment of additional capital in this sector. This would bring about an increased supply of machines and a corresponding fall in their price, and thus lead to the emergence of extra-profits in the machine-using industries. Non-proportional sectoral net investments according to capital profitability (and, perhaps, intersectoral capital movements) would then bring about a tendency towards a uniform profitability of capital in all industries, given the real wage rate.

Kähler clearly recognized that a proper dynamic analysis would have to study these simultaneous adjustments of relative prices and sectoral quantities. However, in order to simplify the analysis, he adopted a two-step procedure. In a first step he assumed that the old price system remains valid throughout the entire compensation phase. This implies that the phenomenon of the economic obsolescence of (a part of) the existing capital stock is set aside. Kähler was aware of this fact. He maintained, however, that the incorporation of this aspect would generally result in additional labour displacement.

> The capital stock that exists in a specific physical form cannot simply be transformed into a new use form after an invention. This fact slows down the introduction of technical progress. . . . But it also entails a great danger. If the new inventions are sufficiently productive they can make the old equipment completely obsolete. . . . The emergence of labour displacement would then not only result from the increase in the capital intensity, but also from the destruction of the real capital that has been made obsolete. (Kähler, 1933, p. 139)

(iv) Price adjustments and redistribution of productivity gains. In the final step of his analysis Kähler then tackled the problem of the redistribution of the productivity gains, the establishment of a new system of relative prices, and the associated

revaluation of the capital stock. He maintained that, with the attainment of the full employment level (of the original 1000 labour units) the real wage rate would rise, because of the increased competition for workers. It would continue to rise, Kähler argued, until the technological extra-profits have been completely eroded. He therefore supposed that the economic system would finally settle down in a new stationary equilibrium in which the technological extra-profits have vanished in favour of higher wages (see Scheme IV).

With the elimination of the technological extra-profits in the machinery industry (that is, with the establishment of a new uniform rate of profits at $r = 0$) a new system of relative prices must obtain:

> As long as the profits exist, the 1000 units of labour must receive 1000 commodity units (in the old sense). But after the elimination of profits they must receive 37,5 units in addition. In the new scheme without profits one would therefore either have to raise the value of labour or reduce the value of each of the commodity units from 1037,5 to 1000.... But the devaluation of the commodities can of course not be uniform, because the productivity increase affects directly only the production of machines. However, if we devalue the machines, then we automatically also devalue all the products in whose production the machine is used. On our assumptions, the values of *all* the commodities would be affected, and the more so the larger is the proportion of machines in their production costs. But if, for instance, the value of coal is reduced, then also all the commodities that are produced by coal are reduced in value, and so on. We have calculated these reductions in the values of the commodities *by means of a general system of equations*, in which now 1000 units of labour are equal in value to 103,7 original units of coal + 207,5 units of machines + 207,5 units of buildings + 518,7 units of agricultural products. (Kähler, 1933, p. 123; emphases added)

Kähler's Table IV can thus be interpreted as follows. With the elimination of the technological extra-profits there is a (proportional) increase in the components of the workers' consumption bundle, denoted by vector $\tilde{\mathbf{c}}$. Hence, the new matrix of the production and consumption coefficients is

$$\tilde{\tilde{\mathbf{A}}} = \begin{pmatrix} 0.2 & 0.5 & 0.1 & 0.1 & 0.1037 \\ 0.1 & 0.17 & 0.1 & 0.1 & 0.2075 \\ 0.1 & 0.08 & 0 & 0.2 & 0.2075 \\ 0.1 & 0 & 0.1 & 0.1 & 0.5187 \\ 0.5 & 0.17 & 0.7 & 0.5 & 0 \end{pmatrix}$$

The normalization of the initial scheme, that is, the normalization

$$w = \tilde{\mathbf{p}}^{\mathrm{T}}\mathbf{c} = \tilde{\mathbf{p}}^{\mathrm{T}}(0.1, 0.2, 0.2, 0.5)^{\mathrm{T}} = 1$$

is replaced by the new normalization

$$\tilde{w} = \tilde{\tilde{\mathbf{p}}}^{\mathrm{T}}\tilde{\mathbf{c}} = \tilde{\tilde{\mathbf{p}}}^{\mathrm{T}}(0.1037, 0.2075, 0.2075, 0.5187)^{\mathrm{T}} = 1$$

From $\tilde{\mathbf{p}}^{\mathrm{T}}(\mathbf{I} - \tilde{\tilde{\mathbf{A}}}) = \mathbf{0}^{\mathrm{T}}$ and $(\mathbf{I} - \tilde{\tilde{\mathbf{A}}})\mathbf{x} = \mathbf{0}$, the new prices and quantities are determined as

$$\tilde{\mathbf{p}}^{\mathrm{T}} = (0.982, 0.888, 0.985, 1) \text{ and } \mathbf{x}^{\mathrm{T}} = (551, 450, 437, 686, 1000).$$

Scheme IV (=scheme III, adjusted to the new exchange relations)

	Flows and Stocks in the production of										
	Coal and iron		Machines		Buildings		Agriculture		Labour		
Inputs	Flow	Stock	Flow	Stock	Flow	Stock	Flow	Stock	Flow	Stock	Total
Coal and iron	108.3	7.2	221	36.7	42.9	31	67.3	16.6	101.8	29.4	541
Machines	48.9	242.7	66.6	666	38.8	189.9	60.9	224.4	184.2	177.6	399
Buildings	54.3	430.7	36.9	369.2			135.1	829.7	204.3	1970	430
Agriculture	54.1	6.1			42.9	30.9	67.3	72.4	509.4	9.8	673
Labour	275.7	30.3	75	14.1	306.1	221.2	343.1	263			1000
Total production	541	717	399	1086	430	473	673	1406	1000	2186	

Total stock of productive capital = 3682, Total wages = 1000, Productive capital : Total wages = 3.68.

It should be noted that the figures in Kähler's Table IV—unlike those in the Tables I, II and III—do not refer to physical quantities.[13]

(v) The choice of technique problem. In the final section of his treatise, Kähler also tackled the problem of the choice of technique by means of simple numerical examples (Kähler, 1933, pp. 125–131). In these examples, alternative methods of production that differ in terms of their 'cost composition' are compared at different wage levels. By means of these exercises in comparative statics Kähler sought to investigate the question of whether, after the new method had been introduced and a part of the labour force had been displaced, a return to a full employment situation could be accomplished by reducing the real wage rate. More specifically, he asked whether, in such a situation, a wage reduction is 'capable of eliminating the greater profitability of the more capital-intensive technique' (Kähler, 1933, p. 126), and thus could induce producers to switch back to the method that was previously in use. Although Kähler's analysis is deficient in several respects, it nevertheless contains some interesting observations. In particular, the following features deserve mentioning. First, following the classical authors, Kähler investigated the problem of the choice of technique by starting from a given real wage rate (which is then varied parametrically). Secondly, he pointed out that, for any given technique, there exists an inverse relationship between the wage rate and the rate of profits (Kähler, 1933, pp. 125–26). Thirdly, he emphasized that, in the case of zero profits, that is, when the labour theory of value holds, 'then every technical innovation is profitable which reduces the labour input requirement per unit of the social product' (Kähler, 1933, p. 129). Finally, he demonstrated that in his (partial analysis) framework, a wage reduction can eliminate the greater profitability of the more capital-intensive method only if the latter is associated with a relatively small increase in the output per worker in relation to the increase in its capital-intensity. However, Kähler's analysis of the problem of the choice of production methods was carried out in a partial framework of the analysis, which does not account for sectoral interdependences.

5. Kähler's Model and the Models Employed in Some Recent Input–Output Studies

In this section the model developed by Kähler is briefly compared with the one that was recently employed by Leontief & Duchin (1986) in their empirical input–output study.[14] As is well known, the theoretical core of this study consisted of a dynamic input–output model, in which the sectoral amounts of investment were determined endogenously for each period, while all the other components of final demand, that is, household consumption, government consumption and exports, were determined exogenously. The Leontief–Duchin model is a pure quantity model. It is first solved for the output vector $\mathbf{x}(t)$ in period t; then the vector of labour requirements by occupation, $\mathbf{e}(t) = \mathbf{L}(t)\mathbf{x}(t)$, is computed for period t (see Leontief & Duchin, 1986, pp. 132–38). In order to investigate the future impact of automation on workers, the authors chose to apply a scenario technique: they first computed the employment path for a reference scenario (S1), which assumes no technical progress after a certain base year (1980), and then computed various other scenarios (S2, S3, S4) with alternative assumptions about the speed of technological change and/or the development of final demand (Leontief & Duchin, pp. 5–12). A similar model was also used in a study by Edler (1990), who investigated the impact of the introduction of industrial robots on the (West) German economy.[15] A modified version of Leontief & Duchin's dynamic input–output model, which contained a much more sophisticated investment hypothesis, was introduced in the study of Kalmbach & Kurz (1992).

What are the major differences between Kähler's model and the models that were employed in these studies? First, the use of a dynamic input–output model allows determination of the time path of output and employment, while Kähler's model is confined to comparative static analyses. Secondly, the application of the scenario technique allows to test the robustness and sensitivity of the results by comparing the implications of various alternative assumptions. Thirdly, none of the modern input–output studies incorporates a proper price model. For this reason there is neither an analysis of the choice of technique problem nor an analysis of the impact of technological change on relative prices and income distribution. This implies that all displacement and compensation effects which are associated with price-, income- and redistribution effects, cannot be taken into account.

6. Concluding Assessment

In his pioneering study of 1933, Alfred Kähler integrated the classical theory of labour displacement and compensation with the analysis of the economic circular flow. His major analytical contribution consisted of the elaboration of a multi-sectoral model of the economy as a basis for the analysis of the employment effects of new technologies. Kähler sought to capture these effects by means of a sequence of different (static) input–output tables, which were meant to capture the state of the economic system in different phases of the transition from an 'old' to a 'new' technique. That this was a major step towards the development of an appropriate theoretical framework is confirmed by the recent publication of several empirical input–output studies that seek to investigate the future impact of automation on workers on the basis of dynamic input–output models.

Notes

1. A comprehensive assessment of Kähler's contribution in the context of the so-called 'German rationalization debate' has been provided by Mettelsiefen (1981, 1983). This paper draws partly on Mettelsiefen's work.
2. For an account of Kähler's academic career and additional biographical details, see Gehrke (2000) and Hagemann (1999).
3. Leontief submitted his thesis at the University of Berlin, with Werner Sombart and Ladislaus von Bortkiewicz serving as first and second referee respectively. To the best of my knowledge, Wassily Leontief never mentioned Alfred Kähler's pioneering contribution of 1933 in his own writings. Adolph Lowe, who considered Kähler's dissertation thesis to be easily good enough to qualify as a habilitation thesis, suggested that this was motivated by Leontief's desire to dissociate his own work from the Classical-Marxian tradition that had inspired the work of the 'Kiel school' economists.
4. See Ricardo (1951 [1821], ch. 31).
5. See Marx (1989 [1861–63], pp. 177–200).
6. As will be seen below, Kähler's price system is chosen in such a way that the 'cost composition' coincides with the physical input composition of the different commodities.
7. All translations from Kähler (1933) are mine.
8. For a summary assessment of Kähler's analysis of other types of technical progress see Mettelsiefen (1981, pp. 139–151) and Mettelsiefen (1983).
9. The third column, which shows the cost composition of the new production method in the machinery industry, will be explained below.

10. There is no need for a 'correction' of Kähler's Scheme Ia, as proposed by Mettelsiefen (1981, p. 150). Mettelsiefen apparently failed to notice that Kähler altered the 'sum of the cost components' (from 10 to 12).
11. Alternatively, the element a_{52} in matrix $\tilde{\mathbf{A}}$ could be given as '0.17', that is, as the new numerical value of the 'labour input per unit of output'. However, in this case the technological profit would have to be conceived of as a surplus that is generated in the economic system, and Kähler's Scheme III could no longer be interpreted as a closed Leontief model.
12. Kähler seems to overlook that the continuous accumulation of capital does not only cause an increase of the total stock of productive capital but also of the annual profits. If we incorporate the growth factor, the compensation period reduces to approximately 23 years.
13. Mettelsiefen (1983, pp. 239–242) misinterpreted Kähler's approach to the calculation of the new price system and (incorrectly) criticized him for having introduced an *ad hoc* transformation of the production coefficients.
14. It should be noted that, immediately after his emigration to the USA, Kähler also made an attempt to approach the problem of technological unemployment empirically (see Kähler, 1935). He sought to ascertain the amount of technological unemployment in the US manufacturing sector during the 1920s, using various time series of capital stock measures and employment figures.
15. For another empirical input–output study which investigated the impact of automation on workers, see OIW (1981).

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