

A Reappraisal of Ricardo's Principles

On measuring technical change

By
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PREFACE

David Ricardo starts the second and third edition of his *Principles*² as follows:

The value of a commodity, or the quantity of any other commodity for which it will exchange, depends on the relative quantity of labour which is necessary for its production, and not on the greater or less compensation which is paid for that labour.

This principle needs a thorough reappraisal. According to Ricardo competition ensures that the exchange values of all commodities, whose supply can change by spending more or less labour on their production, will gravitate to their real values, that is the relative quantity of labour which is necessary for their production. When the exchange values of commodities thus change over time, "it would be desirable to have the means of ascertaining which of them fell and which rose in real value, and this could be effected only by comparing them one after another with some invariable measure of value, which should itself be subject to none of the fluctuations to which other commodities are exposed. Of such a measure it is impossible to be possessed, because there is no commodity which is not itself exposed to the same variations as the things, the value of which is to be ascertained; that is, there is none which is not subject to require more or less labour for its production"³.

¹ Your writer is an older man who read and reformulated, carefully and full of understanding, the ideas laid down, not always accessible, in the thesis *On Absolute Value and the Value in Exchange of Commodities* and a *Note* to that thesis. Both are written by a student in the early seventies of the last century. The note describes how to measure technical change. The title of his thesis undoubtedly refers to the unfinished paper *Absolute Value and Exchangeable Value* which David Ricardo wrote just before his sudden death in September 1823.

² D. Ricardo, *On the Principles of Political Economy and Taxation*, Volume I of 'The Works and Correspondence of David Ricardo', ed. by P. Sraffa, Cambridge, 1951 (to be referred to as *Principles*).

³*ib.* p. 43-44.

Moreover, Ricardo had to admit that even if there would be a commodity for which, “the same quantity of labour should at all times be required, still it would not be a perfect standard or invariable measure of value”⁴. He was after all very well aware that a commodity produced in one day by 100 labourers cannot be the same in exchange value as the commodity of one labourer who needs 100 days for producing it. By the greater length of time which must elapse before the second commodity can be brought to market, it needs to have a higher value to compensate the employer who had to advance wages for 100 days.

Due to the apparently inextricable relationship with the distribution of income between the wages paid to labourers and the income earned by their employers Ricardo had to speak of the difficult subject of value. He saw no chance of properly integrating his principles explaining the distribution of income into a system that also includes his first principle quoted above.

In this paper we solve his problem: we no longer look for a commodity as an invariable measure of value, but instead declare that the value of a varying total net production of commodities produced by means of commodities and a constant quantity of labour is invariable over time. By looking at the net production of a society from period to period, we are able to infer both from the prices at which the commodities are exchanged for each other and from the quantity of labour used in their production processes where and when, in which production process, the production circumstances of a commodity change in terms of direct and indirect labour. For this measurement of technical change, as explained in section 2 and 3, we do not need to know how the revenues of the net production are distributed between the labourers and their employers. The distribution of income appears to be irrelevant. Nor do the prices of commodities have to reflect the relative quantities of labour which are necessary for their production. By declaring the value of the total net production of labour invariable over time we do not have to wait until the exchange values of commodities had been gravitated towards their real values. Instead, we are able to deduce directly from market prices, despite all the fluctuations they may exhibit, where and when production circumstances have changed. And when the labour force of a society grows, there is a simple correction mechanism as a result of which we are still able to determine exactly where and when less direct and/or indirect labour is needed.

Once measuring technical change has been put into practice, it will become clear where, in which firms, the most efficient production is taking place. And then another fact reveals itself. The most efficient production method, as determined in accordance with the first principle of Ricardo, does not necessarily correspond to the method that would be most efficient according to the neoclassical theory. According to this theory, the most efficient production is characterized by equality of marginal costs and marginal revenues. And as the theory continues, if all firms maximize their profits in this way they will also determine the income distribution.

The thorough reappraisal of the first principle of Ricardo alludes to the hypothesis that in addition to firms that maximize their profits according to neoclassical theory, there may also be firms that produce more efficiently. That this hypothesis may well be true appears from the fact that within the context of a vintage model it can be proven that the most efficient and thus most profitable way of

⁴ *ib.* p. 44.

production is independent of wages and prices: it is determined exclusively by the physical characteristics of the production process⁵.

Given the rather simple production processes of the early nineteenth century, it is quite possible that a firm, at that time most efficient according to Ricardo's principle, also met the conditions of equality between marginal costs and marginal revenues. It is even possible that the exchange value of the commodities produced by this firm, while 'competition operates without restraint', as Ricardo supposed, would differ only slightly from their real value⁶.

But as capital formation increases and production processes become more complex, measuring technical change may very well show that firms emerge that produce more efficiently than those that continue to produce according to the neoclassical theory. In that case, the wage and price-formation will still continue to reflect the equality of the marginal costs and marginal revenues of the last firms, but it depends on the way in which the more efficient firms use their market power in which direction the development goes. By lowering prices they can choose to increase their market share at the expense of the less efficient firms. But they may also decide to benefit longer from the wages and prices set by these less efficient firms and use their higher profits to invest in new even more profitable production techniques. Measuring technical change will thus show how in a very natural way oligopolistic competition⁷ may arise which can still be called a competition without restraint, although it will be clear that this competition may obstacle the gravitation of the exchange values of commodities towards their real values. At the same time, it makes the income distribution less easy to derive.

Before entering into the question how to measure technical change, we will first show in section 1 how our student was inspired by Ricardo and started to get around the interference with the income distribution that hampered Ricardo in his search for an invariable measure of value. Section 2 and 3 follow with an explanation of measuring technical change, which no longer interferes with the income distribution. Thereafter we will discuss all the circumstances and particularities brought to the attention by Ricardo, with special attention to how capital formation should be included in measuring technical change. Section 5, finally, starts to analyse how the thoughts of Ricardo have influenced his contemporaries and the development of economic theory. Especially the lengthy correspondence on the influence of capital turns out to be no less than a prelude to the neoclassical theory. Subsequently, this section will touch on the consequences that measuring technical change has for economic science by showing how the complex reality can be better described and understood with the factual evidence obtained by that measurement.

⁵ A.C. Moons, *Oligopolistic competition and economic development*, OCfEB Research Memorandum 9611, Erasmus University Rotterdam, 1996 (presented at EEA-ESEM congress, Istanbul).

⁶ After discussing all the problems Ricardo encountered in his search for an invariable measure of value, he noted "that the effect on the relative price of things, from a variation in profits, is comparatively slight; that by far the most important effects are produced by the varying quantities of labour required for production", *Principles*, p. 45.

⁷ The vintage model presented in the paper mentioned in footnote 5, was applied to the manufacturing industry of US, Germany, France and UK. It is being investigated whether the actual development of investment from 1960 onwards can reasonably well be explained by a varying market share of 'Schumpeterian' and 'Marshallian' firms. This empirical analysis has been thoroughly revised and applied to 1960-2018 in addition to the earlier period 1960-1993.

On measuring technical change

SECTION 1

The concept of real value and the search for an invariable measure of value. How the solution of defining the real value of the total net product of labour as invariable over time emerges from the discussion between Ricardo and Malthus.

David Ricardo refers extensively to Adam Smith to make the concept of real value as clear as possible for early stages of society.

In speaking then of commodities, of their exchangeable value, and of the laws which regulate their relative prices, we mean always such commodities only as can be increased in quantity by the exertion of human industry, and on the production of which competition operates without restraint.

In the early stages of society, the exchangeable value of these commodities, or the rule which determines how much of one shall be given in exchange for another, depends almost exclusively on the comparative quantity of labour expended to each.

“The real price of every thing,” says Adam Smith, “what every thing real costs to the man who want to acquire it, is the toil and trouble of acquiring it. What every thing is really worth to the man who has acquired it, and who wants to dispose of it, or exchange it for something else, is the toil and trouble which it can save to himself, and which it can impose upon other people.” “Labour was the first price – the original purchase-money that was paid for all things.” Again, “in that early and rude state of society, which precedes both the accumulation of stock and the appropriation of land, the proportion between the quantities of labour necessary for acquiring different objects seems to be the only circumstance which can afford any rule for exchanging them for one another. If among a nation of hunters, for example, it usually cost twice the labour to kill a beaver which it does to kill a deer, one beaver should naturally exchange for, or be worth two deer. It is natural that that what is usually the produce of two days’, or two hours’ labour, should be worth double of what is usually the produce of one day’s, or one hour’s labour.”

That this is really the foundation of the exchangeable value of all things, excepting those which cannot be increased by human industry, is a doctrine of utmost importance in political economy; for from no source do so many errors, and so much difference of opinion in that science proceed, as from the vague ideas which are attached to the word value.

If the quantity of labour realized in commodities, regulate their exchangeable value, every increase of the quantity of labour must augment the value of that commodity on which it is exercised, as every diminution must lower it.⁸

But these rules, which regulate relative prices, are also largely applicable in more advanced stages of society. Ricardo stresses: “If we look to a state of society in which greater improvements have been made, and in which arts and commerce flourish, we shall still find that commodities vary in value conformably with this principle: in estimating the exchangeable value of stockings, for example, we

⁸ *Principles*, p. 12-13.

shall find that their value, comparatively with other things, depends on the total quantity of labour necessary to manufacture them, and bring them to market”⁹.

I do not want to bother you with his extensive description of the various production processes that have to be passed before the manufactured stockings come to the market, I rather show how our student was captivated by the conviction that it must be possible to deduce from the values in exchange when and where less labour is required for the production of one or another commodity.

But our student was also triggered¹⁰ by the Ricardo’s confusion that it cannot “be correct, to say with Adam Smith, ‘that as labour may sometimes *purchase* a greater, and sometimes a smaller quantity of goods, it is their value which varies, not that of the labour which purchases them’ and therefore, ‘that labour *alone never varying in its own value*, is alone the ultimate and real standard by which the value of all commodities can at all times and places be estimated and compared’.”¹¹ When our student looked up these quotes in the *Wealth of Nations* he read from a few lines earlier (the underlined words were inserted by our student):

The product of “equal quantities of labour, at all times and places, may be said to be of equal value”. The value of this product “must always be the same, whatever may be the quantity of goods”. This product, indeed, may sometime consist of “a greater and sometimes a smaller quantity; but it is their value, the value of the separate commodities, which varies, not that of the total product of labour.” The product of “labour alone, therefore, never varying in its own value, is alone the ultimate and real standard by which the value of all commodities can at all times and places be estimated and compared”¹².

With the solution already at hand, it remains important to base principles on reality, a reality in which the total product of labour is divided between wages, profits and rent. “Even in that early state to which Adam Smith refers,” says Ricardo, “some capital, though possibly made and accumulated by the hunter himself, would be necessary to enable him to kill his game. Without some weapon, neither the beaver nor the deer could be destroyed, and therefore the value of these animals would be regulated, not solely by the time and labour necessary to their destruction, but also by the time and labour necessary for providing the hunter’s capital, the weapon, by the aid of which their destruction was effected.”¹³

Ricardo has rightly stressed that we have to look to the actual exchange values of commodities as a result of actual demand and supply on the markets. Assuming that these values always gravitate to their real values when competition operates without restraint, he was convinced that it must be possible to derive from the actual exchange values for which commodities the real values have changed over time.

⁹ *ib.* p. 24.

¹⁰ Our student might have been even more triggered by the following passage that only occurs in the first and second edition of the *Principles*: “It will be seen by the extract which I have made in page [13], from the ‘Wealth of Nations’, that though Adam Smith fully recognized the principle, that the proportion between the quantities of labour necessary for acquiring different objects, is the only circumstance which can afford any rule for our exchanging them for one another, yet he limits its application to ‘that early and rude state of society, which precedes both the accumulation of stock and the appropriation of land;’ as if, when profits and rent were to be paid, they would have some influence on the relative value of commodities, independent of the mere quantity of labour that was necessary to their production.

Adam Smith, however, has nowhere analyzed the effects of the accumulation of capital, and the appropriation of land, on relative value. It is of importance, therefore, to determine how far the effects which are avowedly produced on the exchangeable value of commodities, by the comparative quantity of labour bestowed on their production, are modified or altered by the accumulation of capital and the payment of rent.”, *ib.* p. 22-23.

¹¹ *ib.* p. 16-17.

¹² Adam Smith, *An Inquiry into the Nature and Causes of the Wealth of Nations*, Book 1, Chapter V, p. 47, edited by E. Cannan, Bantam Books, New York, 2003.

¹³ *Principles*, p. 22-23.

However, he also recognised that in view of the actual wages and profits and the use of machinery and other fixed and durable capital there is “another cause, besides the greater or less quantity of labour necessary to produce commodities, for the variation in their relative value – this cause is the rise or fall in the value of labour.”¹⁴ “It appears, then, that in proportion to the quantity and durability of the fixed capital employed in any kind of production, the relative prices of those commodities on which such capital is employed, will vary inversely as wages; they will fall as wages rise, and rise as wages fall”¹⁵. These relative variation in exchangeable value from a rise or fall of wages hampered Ricardo in his search for an invariable measure of value that is “perfectly accurate”.

The interrelation between the search for a perfect measure of value and the rules that determine the distribution of the product of labour between wages, profits and rent will return in the analysis of section 4 and 5. The present section ends with a couple of clues to what inspired our student when he read the extensive correspondence between Ricardo and Malthus. Which ideas and fragments of their discussion underlie his method to measure technical change?

I think that Malthus in his *Measure of Value*– written after years of discussion with Ricardo to make his position crystal clear¹⁶ – provides a good starting point. In his introduction Malthus also refers to Adam Smith: “In laying down labour as a measure of value, it is allowed that he does not make it quite clear, whether he means the labour which is worked up in a commodity, or the labour which it will command”¹⁷. In contrast to Ricardo who is especially interested in the labour worked up in commodities, Malthus considers “the labour which commodities will command ... as a standard measure of their natural and exchangeable value”¹⁸. According to Malthus, the natural price of commodities (“this must necessarily be the same as the quantity of labour which they will command”¹⁹) equals the sum of the usual wages, profits and possibly also rents necessary to their production. He clearly distances himself from Ricardo and – according to our student – rightly emphasizes that the profits necessary for production can be “so considerable as to destroy the proposition that commodities exchange with each other according to the quantity of labour which has been employed upon them”²⁰. But more importantly, he clarifies his position with the aid of an intriguing table that shows how the quantity of corn, produced by given number of workers, changes in response to a more or less fertile soil. From this table he draws the conclusion “that the quantity of labour required to produce the wages of a given number of men, with the addition of the profits upon these advances estimated in labour, must always be exactly the same as the quantity of labour which the wages will command”²¹. In response to the question how it comes about that labour should remain of the same value when it requires more labour to produce the same quantity of corn, he answers “that as profits depend upon the proportion of the whole product which goes to labour, it must necessarily happen that the increase of value occasioned by the additional quantity of labour will be exactly counterbalanced by the diminution in the amount of profits, leaving the value of the

¹⁴ *ib.* p. 30.

¹⁵ *ib.* p. 43.

¹⁶ In November 1821, Malthus and Ricardo found that little added value was to be expected from continuing their private discussion about value, but that a public discussion “might do some good to the public”, letter from Ricardo to Malthus, 27 November 1821, *Letters July 1821-1823*, Volume IX of ‘The Works and Correspondence of David Ricardo’, ed. by P. Sraffa, Cambridge 1951 (to be referred to as *Letters IX*) p. 113.

¹⁷ T. Malthus, *The Measure of Value Stated and Illustrated, with an Application of it to the Alterations in the Value of the English Currency since 1790*, 1823, reprint 1957, New York (to be referred to as *Measure of Value*) p. iii.

¹⁸ *Measure of Value*, p. v.

¹⁹ *ib.* p. 16.

²⁰ *ib.* footnote p. 12-13.

²¹ *ib.* p. 38-39.

labour the same”²². In section 4 we will clarify these apparently puzzling clues by returning to this table that combines differences in the production circumstances of corn with differences in wage levels, while the table in determining the rate of profits serves as a pars pro toto for an entire economy.

it is a pity that Ricardo was not given the time to understand the table properly. He could then have written that Mr. Malthus does in fact nothing else but declare the product of a constant quantity of labour invariable in value over time, which would enable him to focus on determining the change in the real value of the corn in those fluctuating production circumstances. Section 4 begins by showing how both approaches to the concept of value complement each other. In building the bridge between the aggregated level provided by Malthus and the ultimate goal of Ricardo (which is: how to derive from the exchangeable values for which commodities the production circumstances have physically changed) our student was undoubtedly also inspired by *Absolute Value and Exchangeable Value*. In this unfinished paper Ricardo discusses the possibility to call the product of a great number of men as invariable in value over time²³. So, it seems that all fragments of the method to determine technical change have already been provided by Ricardo and Malthus.

SECTION 2

Measuring technical change: the case of firms producing commodities by use of direct labour only.

To demonstrate measuring technical change we use a multi sector economy. Each sector that includes one or more firms produces identical commodities which differ from the commodities produced by other sectors. The commodities of one, arbitrarily chosen, sector function as numeraire: their price is always equal to one. The exchange values of the commodities of the other sectors are expressed in the numeraire. For determining the technical change these values do not have to reflect their real value. In fact it does not matter how these exchange values fluctuate. There is only one restriction: the total product of each sector must have a positive value.

In this section each sector uses direct labour only to produce commodities. The quantity of labour in each sector i in period t is given by l_i^t , the quantity of produced commodities by q_i^t and their exchange value by p_i^t . Then we have for each sector result $r_i^t = p_i^t q_i^t$. The total result tr^t for all sectors together follows from $tr^t = \sum_i r_i^t$ and the total quantity of labour of the whole economy from $tl^t = \sum_i l_i^t$. Moreover, we define for each sector the result per labourer $rl_i^t = r_i^t / l_i^t$ as well as the average result per labourer for the whole economy $tr^t = tr^t / tl^t$. Note that we do not define which part of the result per labourer goes to that worker as a wage.

Next we define for each sector i the variable $rp'rl_i^t$, which shows the relative exchange value of commodity i in comparison with the relative result per labourer. So,

²² Letter from Malthus to Ricardo, 21 July 1923. *Letters IX*, p. 308-309.

²³ D. Ricardo, *Absolute Value and Exchangeable Value*, in: *Pamphlets and Papers 1815-1823*, Volume IV of ‘The Works and Correspondence of David Ricardo’, ed. by P. Sraffa, Cambridge, 1951 (to be referred to as *Absolute Value and Exchangeable Value*), p. 400-402.

$$rp'rl_i^t = \frac{\frac{p_i^t}{tr^t}}{\frac{r_i^t}{tr^t}}$$

Note that in the numerator the exchange value of a single commodity i is expressed in the total value of all commodities, while in the denominator the result per labourer of sector i is expressed in the result per labourer of all sectors together.

The technical change ρ_i^t from period $t-1$ to period t for sector i follows then from the next equation:

$$\rho_i^t = \frac{rp'rl_i^{t-1} - rp'rl_i^t}{rp'rl_i^{t-1}} \quad (1)$$

For reasons of simplicity our multi sector economy is presented here as a three sector economy, although the accompanying Excel file refers to five sectors. The technical change is then determined by:

$$\begin{bmatrix} rp'rl_1^{t-1} \\ rp'rl_2^{t-1} \\ rp'rl_3^{t-1} \end{bmatrix} = \begin{pmatrix} \frac{1}{1-\rho_1^t} & \frac{1}{1-\rho_2^t} & \frac{1}{1-\rho_3^t} \end{pmatrix} \begin{bmatrix} rp'rl_1^t \\ rp'rl_2^t \\ rp'rl_3^t \end{bmatrix}$$

Within the Excel file you are free to change the input of labour, the quantity of the produced commodities and their exchange values: time after time the Excel file will show the right technical change. There is only one automatic correction because the determination of the technical change will only provide the right technical change if the total use of labour in period $t-1$ equals the total use of labour in period t . If these totals are not equal, the whole economy in period $t-1$ will be linearly scaled to provide the requested equality. This equality expresses the fundamental principle underlying this measurement of technical change: the total net product of a constant quantity of labour in a society must be called invariable in value over periods of time.

It should be noted that the description of the multi sector economy also provides all information in order to determine the technical change from the physical production processes of each sector in a direct way. So, we can check in the Excel file whether the above proposed measurement of technical change provides the right answers. The technical change directly derived from the physical production processes follows from changes in labour per commodity produced:

$$\rho_i^t = \frac{\frac{l_i^{t-1}}{q_i^{t-1}} - \frac{l_i^t}{q_i^t}}{\frac{l_i^{t-1}}{q_i^{t-1}}} \quad (2)$$

You may wonder why to rely on such a complicated measurement of technical change, focused on both the relative value in exchange of a commodity and the relative result per labourer in the sector that produces that commodity, if the technical change could also directly be derived from the quantity of commodities produced by a sector and the quantity of labour necessary for their production? You may also wonder whether a simplification of this complex measurement ultimately amounts to exactly the same as the direct measurement of technical change? And you are right: the relative value in exchange divided by the relative result per labourer can be simplified to

$$\frac{l_i^t}{q_i^t \sum_i l_i^t}$$

This means that equation 1 can be rewritten as

$$\rho_i^t = \frac{\frac{l_i^{t-1}}{q_i^{t-1} \sum_i l_i^{t-1}} \frac{l_i^t}{q_i^t \sum_i l_i^t}}{\frac{l_i^{t-1}}{q_i^{t-1} \sum_i l_i^{t-1}}} \quad (3)$$

However, equation 3 can only be equal to equation 2 if $\sum_i l_i^{t-1}$ equals to $\sum_i l_i^t$. This proves the necessity of the underlying condition that the total net product of a constant quantity of labour in a society must be considered as invariable in value over periods of time. This condition brings to life the seemingly used tautologies.

The merits of the concept of measuring technical change based on the relationship between the relative exchange value and the relative result per labourer are evident, not only because of the transparency inherent to the concept, but also because of the greater simplicity that is achieved when intermediate deliveries are taken into account, as we will see in the next section. Moreover, it follows Ricardo: he wanted to deduce from market prices where the production circumstances change. Which firm starts with a new, more labour-saving production technique: that is how your student understood Ricardo's problem and sought a solution in the discussion between Ricardo and Malthus. And what he found he called 'the twofold valuation method'. As soon as the production circumstances change we frequently do not have ex ante knowledge about the peculiarities of the new physical production process. We have to rely on market prices to track these changes.

The strength of the solution becomes particularly evident in the next section, because the technical change of one sector often manifests itself in interaction with the commodities needed in its production process that are produced by other sectors, while technical change may also occur in the production processes of those other sectors. It is precisely through changes in the complex relationships between firms that technical change emerges.

SECTION 3

Measuring technical change within firms that use in their production processes not only direct labour but also commodities produced by other firms.

In order to introduce 'production of commodities by means of commodities'²⁴ we have to extend the description of the multisector economy in section 2. Let q_{ij}^t represents the quantity of the commodities from sector j used in the production process of sector i , and let the price which sector i has to pay for its use of commodity j be the same as sector j receives for its other output, then we have to reformulate for each sector result $r_i^t = p_i^t q_i^t - \sum_{j, j \neq i} p_j^t q_{ij}^t$. Evidently, the use of commodity i as intermediate input by all the other sectors j must be possible by the production of sector i . This

²⁴ Your writer eagerly refers to P. Sraffa, *Production of Commodities by Means of Commodities*, Cambridge 1960.

implies the condition $q_i^t \geq \sum_{j,j \neq i} q_{ji}^t$. It is also evident that the total result for all sectors together, known as $tr^t = \sum_i r_i^t$, represents the net product of the economy²⁵.

The technical production processes of our three sector economy could be describe by

$$\begin{aligned} l_1^t + q_{12}^t + q_{13}^t &= q_1^t \\ l_2^t + q_{21}^t + q_{23}^t &= q_2^t \\ l_3^t + q_{31}^t + q_{32}^t &= q_3^t \end{aligned}$$

It will be clear that the measurement of technical change in section 2 stays the same if we add two unit matrices.

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} rp'r l_1^{t-1} \\ rp'r l_2^{t-1} \\ rp'r l_3^{t-1} \end{bmatrix} = \begin{pmatrix} \frac{1}{1-\rho_1^t} & & \\ & \frac{1}{1-\rho_2^t} & \\ & & \frac{1}{1-\rho_3^t} \end{pmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} rp'r l_1^t \\ rp'r l_2^t \\ rp'r l_3^t \end{bmatrix}$$

However, according to our student we need to change these two matrices in order to measure the technical change of production of commodities by means of commodities as follows. First we focus on the diagonals of both matrices. For each sector i the unit value in each matrix has to be replaced by the value of the production of that sector minus the value of the necessary inputs of other commodities as a fraction of the production value of sector i . So, the unit diagonal shows for each sector i the following expression:

$$\frac{v_i^t q_i^t - \sum_{j,j \neq i} v_j^t q_{ij}^t}{v_i^t q_i^t}$$

Without intermediate input in sector i this expression evidently equals the unit value one.

The sheet 'intermediate step' of the Excel file shows under which restrictions these diagonal expressions help to determinate the right technical change. The next sheet 'direct and indirect labour' shows that the zero values in both matrices for sector i quite simply have to be replaced by the quantity of commodities of sector j , $j \neq i$, that are used as input in sector i divided by the quantity of the produced commodities by sector i . But also that this ratio should be multiplied by the unit diagonal value belonging to sector j . So, every zero within both matrices has to be replaced by

$$\frac{q_{ij,j \neq i}^t}{q_i^t} \times \frac{p_j^t q_j^t - \sum_{i,i \neq j} p_i^t q_{ji}^t}{p_j^t q_j^t}$$

After multiplying the rows of both matrices with the vectors $rp'r/l$ it is easy to determine for each sector the technical change ρ_i^t . The Excel file shows that the measured technical change will be independent of changes in the exchangeable values of the commodities. It also shows how the technical change of sector j could influence the technical change of sector i by the use of commodity j in the production process of sector i . Moreover, the measurement of technical change turns out to be independent of the distribution of the net product of an economy between wages and profits. By defining an index of worked up labour, we are able to see to what extent the commodities of all the different sectors are produced with more or less labour over periods of time.

²⁵ The net product of the multi sector economy (to be divided between wages and profits) has to be positive over time. Production which only consist of mutual deliveries, makes no sense (see also footnote 53). So, we do not assume 'real' wages to be an input that is defined by a given basket of different commodities. In that case each sector would have to buy this basket for every worker needed in its production processes (see for example G. Caravale and D Tosato, *Ricardo and the Theory of Value, Distribution and Growth*, London, 1980, p. 17).

The Excel file also demonstrates that the measured technical change always corresponds with the change directly derived from the physical production processes, which is equal to

$$\rho_i^t = \frac{\frac{l_i^{t-1} + \sum_{j,j \neq i} \frac{q_{ij}^{t-1}}{q_j^{t-1}} l_j^{t-1}}{q_i^{t-1}} - \frac{l_i^t + \sum_{j,j \neq i} \frac{q_{ij}^t}{q_j^t} l_j^t}{q_i^t}}{\frac{l_i^{t-1} + \sum_{j,j \neq i} \frac{q_{ij}^{t-1}}{q_j^{t-1}} l_j^{t-1}}{q_i^{t-1}}} \quad (4)$$

The complexity of equation 4 shows the merits of the twofold valuation method, especially when the method is applied in an appropriate input-output framework provided by a statistical office. In that case a firm that belongs to sector i can distinguish itself from the rest of sector i by creating two subsectors. Besides its own administrative data this firm then only needs to express its necessary inputs from other sectors than sector i as a fraction of the total output of those other sectors in order to determine whether the firm is able to produce more efficiently than the rest of its sector.

Once the twofold valuation for the economy as a whole is determined annually, it is for separate firms easy to determine how their rate of technical change develops in comparison with their competitors. If the index of labour worked up in their commodities shows a relative fall, they know they are producing more efficiently. If these firms have to perform calculations in accordance with equation 4 in order to determine their competitiveness, they would each individually have to collect an enormous amount of data for the economy as a whole. The twofold valuation method provides a framework that firms may strengthen in their search for more efficient production and thereby contributes to a prosperous economic development. The index of labour worked up in commodities of those firms will then show a relative fall.

Because the framework predominantly makes use of actual market prices it also allows analysing firm behaviour. If a firm in a sector starts to produce in a more labour saving way than the other firms in its sector, it gets the possibility to lower its prices and to expand its production at the cost of the firms that lag behind. But this firm can also choose to keep its prices unchanged for some time and to benefit from a relative increase of its profit. As soon as we have introduced the use of machinery and discussed the emergence of the neoclassical theory in the next sections we are able to conclude that, if we had already had the framework in the past, we could have derived from the facts how firms in various sectors frequently start to produce more efficiently than other firms that keep their machinery in operation as long as it provides a positive profit.

But for now it must be stressed at the end of this section that the twofold valuation framework for an economy as a whole has also a value in itself. It shows the pattern of technical change for all sectors of the economy and how the technical change in one sector spread across other sectors if its commodities are used by these other sectors as input. It should also be stressed that the twofold valuation method only measures changes in the labour worked up in commodities from one period to another. In contrast to the method that directly uses the technical production processes, the twofold valuation method is not able to identify the absolute quantity of the direct and indirect labour worked up in commodities in one specific period.

SECTION 4

A closer look at Malthus' table. As well as peculiarities like differences in the quality of labour and the use of machinery that differs in durability and duration.

Malthus has rightly pointed out that the exchangeable value of “the great mass of commodities in civilized and improved countries is made up at least of two element – labour and profits. ... It cannot, then, be said with any thing like an approximation towards correctness, that the labour worked up in commodities is the measure of their exchangeable value”²⁶. On the other hand, Ricardo has rightly assumed that the labour worked up in commodities is decisive for measuring any technical change in the production circumstances of commodities, and that these changes could be derived from their exchangeable values.

And indeed, we have seen how changes in the labour worked up in the production of commodities can be measured, even in the case that their exchangeable values do not reflect the differences in the worked up labour. That means: including the case that the exchangeable values of commodities, according to Malthus, correspond with their “natural price” that “would obviously be equal to the price of the accumulated and immediate labour expended on the commodity, together with the ordinary profits estimated on such advances”²⁷. The twofold valuation method always provides the correct technical change regardless of which prices are involved.

Malthus' “Table illustrating the invariable Value of Labour and its Results”²⁸ is of much use in illustrating how the statements of both Malthus and Ricardo can be consistent with each other. The first six columns of the table below are derived from Malthus' table. The first column of the first row shows that ten men produce 150 quarters of corn. If every labourer earns a wage of 12 quarters of corn, the profits of the employer will be equal to 30 quarters of corn. In percentages of the advanced wages the profit rate will then be 25 per cent, as shown by the third column of the first row. In this case, 8 men are necessary to produce the wages of the ten men ($8 \times 15 = 120$), but Malthus also stresses that the profits estimated in quantity of labour come out at 2 men ($2 \times 15 = 30$).

In the second and third row the production circumstances are identical to the first row. Only the wages are different and therefore also the profits. But, as regards columns 4 and 5, “the reader will see at once that these two columns must necessarily, from the manner in which profits and wages are estimated, make up the constant quantity of labour”²⁹. And even if the production circumstances change, as is the case in the next rows, the total product of ten men can always command the labour of ten men, which, according to Malthus, implies that the value of the wages of a given number of men is invariable. The sum of columns 4 and 5, the 'Invariable Value of the Wages of a given number of Men' as Malthus calls it, is therefore always equal to 10. The value of the product of the labour of ten men under the varying circumstances equals then this invariable value of the wages augmented with the varying rate of profits, as shown by column 6.

²⁶ *Measure of Value*, p. 13.

²⁷ *ib.* p. 14.

²⁸ *ib.* p. 38. Malthus' table (with its implied formulae) is also fully included in an eponymous sheet in the accompanying Excel file.

²⁹ *ib.* p. 37.

Before sharing Ricardo's critical remarks, we apply the twofold valuation method to the economy presented in Malthus' table. This simple economy can help understand the workings of this method better. Because it consists of one sector that produces only one commodity, the denominator of the method, the relative result per labourer, always equals one. After all, the result per labourer of the single sector equals the result per labourer of the total economy. Therefore, all attention can be focused on the numerator: the exchange value of a quarter of corn divided by the total value of the corn produced.

If the corn wage in the first row of the table were equal to 15, the entire production would go to wages leaving the profits equal to zero. In that case, the exchange value of a quarter of corn would be equal to 0.06667 (=10/150), which equals the labour worked up in a quarter of corn. The relative exchange value is then equal to 0.006667 (=10/150)/10). If the distribution of income changes resulting in lower wages and higher profits, both the exchange value of a quarter of corn and the total value of the corn produced increase equally. As a result, the relative exchange value of a quarter of corn remains the same, as column 7 in the table shows³⁰. Changes in the income distribution do not matter.

Malthus' table in accordance with Ricardo's principles³¹

1	2	3	4	5	6	7	8
Quarters of Corn produced by Ten Men, or varying Fertility of the Soil	Yearly Corn Wages to each Labourer, determined by the Demand and Supply	Rate of Profits under the foregoing Circumstances (pr.Ct.)	Quantity of Labour required to produce the Wages of Ten Men under the foregoing Circumstances	Quantity of Profits on the Advances of Labour	Value of the Product of the Labour of Ten Men under the Circumstances supposed (= (4+5)*(1+3/100))	Relative value in exchange of corn divided by the relative result of labour (= ((6/1)/6) / ((6/10)/(6/10)))	Technical change in comparison with the first row production (= 1-7/(7, first row))
150	12	25.00	8.00	2.00	12.50	0.006667	
150	13	15.38	8.67	1.33	11.53	0.006667	0.0
150	10	50.00	6.67	3.33	15.00	0.006667	0.0
130	12	8.33	9.23	0.77	10.83	0.007692	-0.15385
130	10	30.00	7.69	2.31	13.00	0.007692	-0.15385
120	11	9.09	9.17	0.83	10.91	0.008333	-0.25000
120	10	20.00	8.33	1.67	12.00	0.008333	-0.25000

As soon as the soil becomes less fertile and the production of the ten men falls to 130 or 120 quarters of corn, we can again determine the relative exchange value of a quarter of corn and again it turns out to be independent of the income distribution. Column 8 shows how much more labour is needed to produce the same quantity of corn under the deteriorating production circumstances: 15,4 per cent if the production falls from 150 to 130 quarters of corn or 25 per cent in case of a fall to 120. But this change in worked up labour is only correct because in both cases production is accomplished with the same quantity of labour. If the quantity of labour on the less productive soil were to increase from 10 to 11, the entire production process would have to be decreased by 10/11 in order to be able to determine the precise change in the worked up labour. So, it is implicitly assumed here that the product of a constant quantity of labour is invariable in value over time, even

³⁰ The accompanying Excel file contains a more detailed table in which the society consists of two firms that use slightly different prices which induce slightly different relative results.

³¹ In section 1 I called it a pity that Ricardo had not used Malthus' table more explicitly. But his comments on this table in his *Notes on Malthus's 'Measure of Value'*, edited by P. Porta, Cambridge, 1992, are clear: "Now here is the great difference between Mr. M's system and mine, I always estimate the value of corn by a comparison of the whole quantity produced by a given quantity of labour, with such quantity of labour, and not that part only of the whole produce which is paid to the labourers. If 300 qrs. were produced by the labour of 10 men at one time, and at another only 150 qrs. were produced by the same quantity of labour I should say corn had fallen one half in value although there should have been the constant quantity of 120 qrs. paid to the labourers. Mr. M would say that under so great variation in quantity of produce and the facility of producing it the value of it had continued uniformly be the same."

though this invariable value is never expressed in the total exchange value of the commodities produced. It is therefore better to say that the product of an equal quantity of labour is invariable in absolute value. This crucial principle makes it possible to realize Ricardo's ultimate goal, namely to deduce from the market prices where and when of which commodities the production circumstances change.

Ricardo clearly had problems with Malthus' table. He wrote him: "I cannot not agree with you in considering labour, in the sense in which you use it, as a good measure of value. Neither can I discover, exactly, what connexion the constant labour necessary to produce the wages and profits on a commodity, has with its value. If it be a good measure for one commodity, it must be for all commodities"³². Ricardo agrees with Malthus that when labour alone is concerned in the production of commodities, and there is no question of time, both the absolute and exchangeable values of such commodities be accurately measured by the quantity of labour employed upon them. But then he remarks, perhaps somewhat difficult to follow: "Your mistake appears to me this, you shew us that under certain conditions a certain commodity would be a measure of absolute value, and then you apply it to cases where the conditions are not complied with, and suppose it to be a measure of absolute value in those cases also. You appear to me too to deceive yourself when you think you prove your proposition, because your proof only amounts to this, that your measure is a good measure of exchangeable value, but not of absolute value"³³. Malthus did not convince Ricardo of the invariable value of the wages of a given number of men. Ricardo wrote rightly: "I still think that the invariability of your measure is the *definition* with which you set out, and not the *conclusion* to which you arrive by any legitimate argument"³⁴.

I think we can agree with Ricardo. It is by definition that the proceeds of what the ten men in Malthus' table produce can always command the labour that is "immediate" necessary to produce their advanced wages, with the addition of the "accumulated" labour which may even represent "fixed capital of considerable duration". In that case, "there is always a probability that it will alter in value in reference to the quantity of labour, and of profits estimated in labour, of which it was composed when first produced"³⁵. According to Malthus it is necessary "to reckon the remaining value of the fixed capital as a part of the produce resulting from the whole of accumulated and immediate labour employed"³⁶. The sum of both in view of the varying wages and profits must in Malthus' table by definition be equal to ten. Although it could help to determine the comparable exchangeable values of the total produce of ten men by taking the varying wages as numeraire, your writer prefers to determine the value of fixed capital by its replacement costs.

But our student is more lenient with Malthus. He is clearly attracted by the foundation on which Malthus based his theory. "If labour alone, without any capital, were employed in procuring the fruits of the earth, the greater facility of procuring one sort of them compared with another, would not, it is acknowledged, alter the value of labour, or the exchangeable value of the whole produce obtained by a given quantity of exertion. We should, without hesitation, allow that the difference was in the cheapness or dearness of the produce, not of the labour"³⁷. It is indeed the value of the total product of a given quantity of labour that remains invariable over consecutive time periods.

³² Letter from Ricardo to Malthus, 29 April 1823, *Letters IX*, p. 280.

³³ Letter from Ricardo to Malthus, 28 May 1823, *Letters IX*, p. 298-299.

³⁴ Letter from Ricardo to Malthus, 15 August 1823, *Letters IX*, p. 351-352.

³⁵ *Measure of Value*, p. 53.

³⁶ *ib.* p. 53.

³⁷ *ib.* p. 33.

That makes it possible to measure the changes in the real or absolute value of the individual commodities³⁸.

In Ricardo's writings, the concept of absolute value in contrast with exchangeable value barely exceeded his statement "No one can doubt that it would be a great desideratum in political Ec. to have ... a measure of absolute value in order to enable us to know, when commodities alter in exchangeable value, in which the alteration in value had taken place"³⁹. Perhaps it was Malthus who described more clearly what Ricardo meant by absolute value. In his introduction to Ricardo's *Notes on Malthus's 'Measure of Value'*, Porta quotes an article of January 1824 in which Malthus effectively summarizes his difference of opinion with Ricardo. Ricardo, he writes, supposes "that the mass of commodities obtained by the same quantity of labour remains always substantially of the same value, and that the variations of profits are determined by the variations in the value of the same quantity of labour"⁴⁰.

The principle of considering the total product of a constant quantity of labour from one period to another as invariable in absolute value⁴¹ also sheds new light on the peculiarities that Ricardo encountered in his search for a perfect measure of value. Valuating the production of all commodities over equal periods of time solves many of Ricardo's problems. By doing so we start, like Sraffa⁴², valuating the production processes of all different commodities in their mutual connection instead of looking at the value of individual commodities.

*Changes in income distribution no longer matter in case of the unequal rapidity
with which advances to labour are returned to its employer.*

As already mentioned in the preface, Ricardo was well aware of the fact that if wages rise and profits fall a commodity produced in one day by hundred labourers will relatively fall in exchangeable value in comparison with a commodity that one labourer produces in hundred days. The exchangeable value of the last type of commodities consists for a larger part of profits because the employer has to invest longer in the advances of labour before he can bring these commodities to the market. Commodities with a high profit share will relatively fall in exchangeable value if profits fall. Although Ricardo's search for a single commodity as a perfect measure of value was severely hampered by these different influences that changes in income distribution have on the exchangeable value of

³⁸ In his letter to Ricardo of 21 July 1823 Malthus describes the foundation of his theory as follows: "The general concession that the value of commodities is determined by the *quantity* of labour employed upon them, when time is not concerned, is the foundation on which I rest. This foundation once allowed, puts an end at once to all idea of *arbitrary* selection in taking labour as a measure. The other steps follow as strictly as any proposition in Euclid", *Letters IX*, p. 308. And so it is, as section 3 shows.

³⁹ *Absolute Value and Exchangeable Value*, p. 399.

⁴⁰ The quote goes further: "while Adam Smith and Mr. Malthus suppose that the value of the same quantity of labour remains substantially the same, and that the variations of profits are determined by the variations in the value of the commodities produced by this same quantity of labour. In the one case, the varying value of labour is considered as the great moving principle in the progress of wealth; in the other, the varying value of the *produce* of labour". P. Porta, *Introduction to David Ricardo, Notes on Malthus's 'Measure of Value'*, Cambridge, 1992, p. xiii.

⁴¹ Perhaps our student felt also attracted by the following fine words from Ricardo that he addressed to Malthus less than a month before his death and that directly follow the quote to which footnote 34 refers: "My complaint against you is that you claim to have given us a accurate measure of value, and I object your claim, not that I have succeeded and you have failed, but that we have both failed".

⁴² In *Production of Commodities by means of Commodities* Sraffa introduces a standard commodity as "an invariable measure of value" that is "capable of isolating the price-movements of any other product" (p. 18) as a consequence of changes in the distribution between wages and profits. This standard commodity, which is ingeniously derived from the input-output system in such a way that its value does not change in response to any change in the income distribution, enables to determine how the exchangeable values of all commodities react on such changes. But this measure is in no way capable to measure changes in the real value of commodities as a consequence of changes in the physical production circumstances. Simply because of the components of the standard commodity themselves are subject to changes in real value, the measure will no longer be invariable.

commodities, those interrelationships are no longer relevant when applying the twofold valuation method.

However, it is relevant that this method works with successive periods of equal duration. Production of a commodity may then begin in one period and end in the next. For example, in the case of housing production, the index of work-up labour may first show a deterioration, which will be reversed in the next period⁴³. In such cases, the average development over several periods provides insight into the size of the underlying technical change,

*Labour of different qualities differently rewarded.
But for measuring technical change all labourers are equal*

Ricardo was well aware of the different qualities of labour, but he did not see this as a cause of variation in the relative value of commodities. "If a day's labour of a working jeweller be more valuable than a day's labour of a common labourer", it was created long ago. "In comparing therefore the value of the same commodity, at different periods of time, the consideration of the comparative skill and intensity of labour, required for that particular commodity, needs scarcely to be attended to, as it operates equally at both period".⁴⁴

It is striking that Ricardo also attaches less importance to the precise quantity of labour worked up in each commodity: "As the inquiry to which I wish to draw the reader's attention, relates to the effect of the variation in the relative value of commodities, and not in their absolute value, it will be of little importance to examine in which different kinds of human labour are held. We may fairly conclude, that whatever inequality there might originally have been in them, whatever the ingenuity, skill, or time necessary for the acquirement of one species of manual dexterity more than another, it continues nearly the same from one generation to another; or at least, that the variation is very inconsiderable from year to year, and therefore, can have little effect, for short periods, on the relative value of commodities"⁴⁵.

Although the composition of the quality of labour within a firm may show few differences from year to year, there can still be substantial differences between firms that produce the same commodity. Attracting higher qualified labour (which may also be better rewarded) or pursuing a more successful learning by doing policy may increase the competitiveness of a firm relatively. The twofold valuation method may then show that the technical change of such a firm becomes greater than that of its direct competitors. The qualitatively better labour results in relatively less worked up labour in its produced commodities. The increased competitiveness can also lead to a self-reinforcing process if the firm attracts more qualified labour and expands the production at the expense of its competitors.

However, for a proper measuring technical change within a firm, it is not necessary to have explicit insight into the quality of labour. On average over all labourers of an individual firm or of all firms within a branch of industry, these differences will, if they matter, be reflected automatically in the

⁴³ The accompanying Excel file shows a sector with fluctuations in the produced commodities over time because its production takes more than one year. If there is no change in the production technique, the measured technical change may differ from year to year but will nevertheless come to zero on average. If its commodities serve as input for other sectors, the measurement of their technical change will also be temporarily disrupted.

⁴⁴ *Principles*, p. 21.

⁴⁵ *ib.* p. 21-22.

measurement of the technical change. As shown in section 3, differences in wages of labour do not affect measuring technical change.

*The employment of machinery and other fixed capital that differs in durability:
a comprehensive measuring technical change needs two complementary approaches.*

Ricardo describes extensively how the principle that the quantity of labour bestowed on the production of commodities regulates their relative value, changes considerably by the employment of machinery and other fixed capital that differs in durability, and by the unequal rapidity with which this capital is returned to its employer⁴⁶. He concludes that “in proportion to the durability of capital employed in any kind of production, the relative prices of those commodities on which such durable capital is employed, will vary inversely as wages; they will fall as wages rise, and rise as wages fall; and, on the contrary, those which are produced chiefly by labour with less fixed capital, or with fixed capital of a less durable character than the medium in which price is estimated, will rise as wages rise, and fall as wages fall”⁴⁷. But prior to this conclusion Ricardo had already warned us: “The reader, however, should remark, that this cause of variation of commodities is comparatively slight in its effects.” Subsequently, Ricardo highlights the great cause: “Every improvement in machinery, in tools, in buildings, in raising the raw material, saves labour, and enables us to produce the commodity to which the improvement is applied with more facility, and consequently its value alters. In estimating, then, the causes of the variations in the value of commodities, although it would be wrong wholly to omit the consideration of the effect produced by a rise or fall of labour, it would be equally incorrect to attach much importance to it”⁴⁸.

But improvements that save labour may be based on different possibilities. Less labour may be required for the production of new machinery. But instead it is also possible that more labour is needed to make better machinery that, on balance, leads to labour savings in firms that use the new machinery. In addition to the possibility of less required direct labour when operating new machinery, there is also the possibility of saving on indirect labour if the new machinery prevents waste of required raw materials. How could the twofold measurement of technical change enable us to see exactly what is happening in reality? How could we best deal with the impact of the arrival of new machines and other fixed and durable capital? Our student did not want to make any assumption about the rapidity at which the capital becomes obsolete and less useful or about things like an annual depreciation rate. Instead, he sought connection with the chapter *On Machinery* that Ricardo added to the third edition of his *Principles*.

In this chapter, Ricardo shows at a rather aggregated level “that the substitution of machinery for human labour, is often very injurious to the interests of the class of labourers”⁴⁹. These injurious effects can occur if labour is withdrawn from the production of commodities that are necessary for the support of the labourer and his family. Ricardo starts his explanation by assuming initially a rather stationary economy. In addition to fixed capital, the only capitalist of that economy also uses circulating capital that consists of food and necessaries, “all of which he sells in the course of the year

⁴⁶ *ib.* section IV and V, p. 30-43.

⁴⁷ *ib.* p. 43.

⁴⁸ *ib.* p. 36.

⁴⁹ *ib.* p. 388.

to his own workmen for that sum of money, and, during the same period, he pays the like amount of money for wages: at the end of the year they replace in his possession food and necessaries”⁵⁰, just enough to make the usual profit and to continue the production in the following year. “Suppose now, that the following year the capitalist employs half his men in constructing a machine, and the other half in producing food and necessaries as usual. During that year he would pay the ... wages as usual, and would sell food and necessaries to the same amount to his workmen; but what would be the case the following year?”⁵¹ Evidently, by the less produced food and necessaries in the last year “there will necessarily be a diminution in the demand for labour, population will become redundant, and the situation of the labouring classes will be that of distress and poverty.”⁵²

In the next section we will see how, even in modern societies where wages are no longer only determined by what is needed for sustenance, investment may come at the expense of a stable developing consumption that can even lead to long-term unemployment. But for now, it is important that our student has proposed two complementary approaches for a proper measuring technical change induced by capital formation. They are based on Ricardo’s principle that production without consumption is meaningless⁵³. Capital formation is also always aimed at consumption, even though, for example, the construction of a dam with hydroelectric power station can take a lot of time before electricity becomes available to consumers.

The two approaches of the twofold measurement of technical change differ in the definition of the result of firms. In the **first approach** this result equals firm’s revenues from the sale of the produced commodities in consecutive periods of time minus the purchase of both the required intermediary commodities and the new machinery and other fixed capital in those periods. In this approach, the costs outweigh the benefits in the beginning. The new machinery may then cause a rise in the index of worked up labour which will be more than undone the more the machinery is used for more periods of time. In the **second approach** the purchase of new machinery and other fixed capital is not deducted from the result of a firm. This is where the labour-saving effect of new machinery becomes visible immediately after commissioning. For sectors of industry where the new machines are gradually being deployed, the worked up labour index of both approaches may differ only slightly. The two approaches especially prove their worth in the face of more drastic changes that become apparent in initial increases in the worked up labour indices shown by the first approach. Then the second approach can show what is going on.

However, the two approaches can also provide insight into more complex situations, for example when within a sector efficient companies gradually push their less efficient and often less capital intensive competitors out of the market. The decline in the worked up labour index shown by the second approach may then be slowed down in the first approach by an increasing capital intensification.

Results from Excel file

The last three sheets of the accompanying Excel file shows how the measurement of technical change deals with investments of sectors and firms. They show a sector of industry consisting of

⁵⁰ *ib.* p. 388.

⁵¹ *ib.* p. 389.

⁵² *ib.* p. 390.

⁵³ See for instance: “No man produces, but with a view to consume or sell, and he never sells, but with the intention to purchase some other commodity, which may be immediately useful to him, or which may contribute to future production. By producing, then, he necessarily becomes the consumer of his own goods, or the purchaser and consumer of the goods of some other person.” *Principles*, p. 290.

three firms that renew their machinery every three years. It also contains the firm that produces the machinery: each year it delivers one set of machines to one of the three firms. The file shows that for the total of the three firms there is initially no technical change over time, although for each of the three firms there is in the first approach a cycle of a deterioration in the labour worked up in commodities in each year that new machinery is purchased which disappears in the following year.

The file enables us to analyse the arrival of better machinery by which the three firms can enhance their production, although the production of this machinery may require once-only or permanent more labour. In the event that its production requires once-only more labour, the labour worked up in the commodities of the first firm that starts using the new machinery will deteriorate in the first approach more strongly in comparison with the firm that purchases the new machinery the following year. A quite complicated pattern of technical change may then emerge, that becomes easier to interpret if we also look to the pattern resulting from the second approach.

It is also possible that a firm that starts to use more productive machinery may lower its selling prices in order to get a larger share in the demand for its type of commodities. When this demand proves to be quite inelastic it will go at the expense of the competing firms that are lagging behind in purchasing the new machinery. A more detailed pattern of technical change can thus help explain behaviour of competing firms.

However, where the question is whether the technical change is on balance labour-saving, ultimately only the first (integral) approach is relevant. Technical change often depends on the arrival of new machines and other fixed and durable capital. It is therefore important to take into account the production processes of new capital when determining the technical change in the firms that start using that new capital. Its worked up labour must be included in the calculation of the technical change in the production of commodities with that capital. Moreover, in the first approach it is important that the investments of a firm in any year are immediately and completely charged to the result of that firm. After all, we do not know in advance whether these investments will lead to the expected increase in production. Incorrect estimates may mean that large quantities of labour worked up in investment commodities do not ultimately result in labour saving, so that they come at the expense of the production of consumer commodities. If, at an aggregate level, it appears in some year that more labour has been used to produce the same amount of consumer commodities as in the previous year, tensions can arise between wages and prices. The measurement of technical change will reveal such a situation.

The second approach, however, also remains important, especially when it comes to understanding the dynamics of technical change and how the arrival and use of new machinery may directly influence the production circumstances. Especially when the sector that produces investment commodities consists of several firms and only one firm starts offering new and better machines at higher prices. How then do the firms that use the machines respond? The second approach can subsequently help quickly identify the most efficient production.

Measuring technical change in the production of commodities: results from Excel file

Sheet *Overview* of the accompanying Excel file shows for the firms B1, B2 and B3, replacing their machinery every three years, initially no technical change on their aggregate level B, although from the first approach of the two-fold valuation method it appears that the labour worked up in the commodities produced by each firm separately increases in each year of replacement of machinery by 105.3 per cent, followed by a compensating decrease by 51.3 per cent in the next year (see table 1).

Table 1
Index of labour worked up in commodities produced by sector and firm
First approach (no change in production circumstances)

Year	1	2	3	4	5
A	100	100	100	100	100
B	100	100	100	100	100
B1	100	205.2631579	100	100	205.2631579
B2	100	100	205.2631579	100	100
B3	205.2631579	100	100	205.2631579	100
C	100	100	100	100	100

By deploying more labour in year 2, as shown by table 2, sector C succeeds in producing better machines that enable the firms in sector B to increase their production by 50 per cent. The direct labour worked up in commodities of firm B1 will then fall by 33.3 per cent. Table 2 shows that in years of machinery replacement the increase in worked up labour remains limited till 43.9 per cent, followed by a fall of 53.7 per cent. The index of worked up labour then decreases to 66.7 per cent, which is 33.3 per cent lower than the index just before the arrival of the new machines. Because sector A obtains intermediary input from sector B, the labour worked up in commodities produced by sector A is also gradually declining by a total of 9.1 per cent.

Table 2
First approach, changing production circumstance in sector C and subsequently B

Year	1	2	3	4	5
Technical change					
A		0.030303	0.03125	0.032258	0
B		0.120594	0.125	0.111111	0
B1		-0.4386	0.536585	0	-1.15789
B2		0	-0.4386	0.536585	0
B3		0.512821	0	-0.4386	0.536585
C		-0.08333	0	0	0
Index worked up labour					
A	100	96.969697	93.939394	90.909091	90.909091
B	100	87.94063	76.948052	68.39827	68.39827
B1	100	143.8596	66.66667	66.66667	143.8596
B2	100	100	143.8596	66.66667	66.66667
B3	205.3	100	100	143.8596	66.66667
C	100	108.3333	108.3333	108.3333	108.3333

Table 3 shows the results of the second approach. After the purchase of new machines the index of worked up labour in firm B1, B2 and B3 falls directly back to 66.7 per cent. For sector B as a whole, the index gradually falls to the same level. That level is slightly lower than the result of the first approach in table 2. The permanently higher labour worked up in investment commodities keeps the total labour worked up in commodities of sector B on a higher level.

Table 3
Second approach (investments ignored)

Year	1	2	3	4	5
Technical change					
A		0.030303	0.03125	0.032258	0
B		0.142857	0.125	0.111111	0
B1		0.333333	0	0	0
B2		0	0.333333	0	0
B3		0	0	0.333333	0
C		-0.08333	0	0	0
Index worked up labour					
A	100	96.969697	93.939394	90.909091	90.909091
B	100	87.71429	75	66.66667	66.66667
B1	100	66.66667	66.66667	66.66667	66.66667
B2	100	100	66.66667	66.66667	66.66667
B3	205.3	100	100	66.66667	66.66667
C	100	108.3333	108.3333	108.3333	108.3333

The reader is invited to change the parameters on the *Overview* sheet as desired and, for example, to experience that the calculated technical change remains unchanged for firm B1 if it starts lowering its selling prices in order to force firm B2 and B3 to adjust their production level.

SECTION 5

The emergence of the neoclassical theory from the discussion on the difficult subject of value and how its limitations become visible through measuring technical change.

As indicated in the preface: measuring technical change is of utmost importance for a proper approach to Ricardo's principles and laws which regulate the distribution of the whole product of labour within a society between wages, profit and rent. In short, his theory is that "profits depend on high or low wages, wages on the price of necessaries, and the price of necessaries chiefly on the price of food, because all other requisites may be increased almost without limit"⁵⁴. Ricardo describes in detail how less and less fertile land has to be taken into cultivation, with the result that wages rise and farmers' profits fall while the rent income of the owners of land continues to increase. But he also puts this development into perspective: "The natural tendency of profits is then to fall; for, in the progress of society and wealth, the additional quantity of food required is obtained by the sacrifice of more and more labour. This tendency, this gravitation as it were of profits, is happily checked at repeated intervals by the improvements in machinery, connected with the production of necessaries, as well as by discoveries in the science of agriculture which enable us to relinquish a portion of labour before required, and therefore to lower the price of the prime necessary of the labourer"⁵⁵. History shows the increasing importance of these amendments who have come to demand an adjustment of Ricardo's theory about the distribution of income. But your writer likes to point out the underlying principle that still exerts unabated influence, a principle that also refers to equality of marginal costs and marginal revenues:

The exchangeable value of all commodities, whether they may be manufactured, or the produce of the mines, or the produce of land, is always regulated, not by the less quantity of labour that will suffice for their production under circumstances highly favourable, and exclusively enjoyed by those who have peculiar facilities of production; but by the greater quantity of labour necessarily bestowed on their production by those who have no such facilities; by those who continue to produce under the most unfavourable circumstances⁵⁶.

As the discussion on the difficult subject of value continued, Ricardo was well aware that even his admirers dropped out. In a letter to Trower he wrote about McCulloch that the discussion "convinced him, as we all had been long convinced, that the progress of the science is very much impeded by the contrary ideas which men attach to the word value"⁵⁷. Concern about the science has, I believe, already been triggered by the publication of the new chapter *On Machinery* in the third edition of the *Principles* and has been decisive for McCulloch's later comment on the search for an invariable measure of value at distant periods. Whether such a measure exists "is a question which I believe is quite insoluble, but at any rate it does not come within the scope of my inquiries – I leave it

⁵⁴ *Principles*, p. 119.

⁵⁵ *ib.* p. 220.

⁵⁶ *ib.* p. 73.

⁵⁷ Letter from Ricardo to Trower, 24 July 1823, *Letters IX*, p. 312.

to be settled by my masters. ... I am only endeavouring to ascertain the circumstances which determine the comparative values of the commodities in the same market”⁵⁸.

Concern about the progress of science is indeed expressed in McCulloch's letter to Ricardo of 5 June 1821 and is the motive for a strong counter-argument against the “hypothetical” possibility presented by Ricardo in *On Machinery*. “It is what I consider the extreme erroneousness of the principles to which you have incautiously lent the sanction of your name that has excited my principal regret – It is impossible to fritter away your argument by fencing it about with conditions – If it is good for any thing at all it is conclusive against all employment of machinery – It is not with greater or less gross or net produce⁵⁹ that we have the smallest concern in considering this question; but simply whether does machinery produce commodities cheaper or not? If it does *not* produce them cheaper it will not be erected, and if it does produce them cheaper its erection must be profitable to every class of persons”⁶⁰. According to McCulloch, Ricardo may be geometrically right, but the reality is different: as soon as less fertile land threatens to be taken into cultivation with a wage increase as a result, the use of new machines can increase the production of food and other commodities that are essential to the labourer. It is pre-eminently aimed at increasing the production of the commodities that are part of the circulating capital. McCulloch stresses that a manufacturer of clothes can increase his production through the use of machines, just as use of iron ploughs contributes to larger harvests.

But McCulloch also writes: “I admit that if machinery were to become less productive according to the increase of its durability, there might be some force in your reasoning”⁶¹. Here McCulloch alludes to a crucial principle of Ricardo, quoted above, which implies that wages and prices could be determined by the least productive machines. It is as if McCulloch foresaw that, as a result of the ongoing capital accumulation, wages would be less and less determined by the declining productivity of the last land taken into cultivation, but instead increasingly by the relatively declining productivity of the machinery that have been in operation the longest. At the same time, the level of wages was also less and less determined by the prices of food and necessities only, which made the distinction between circulating and fixed capital rather blurred.

Moreover, in the correspondence with Ricardo the emphasis is increasingly placed on the distinction between labour and capital. In this context, Trower for example, who also wants to confine himself to just a measure of exchangeable value, writes that this “subject is rendered more obscure by confounding with immediate labor, what is called accumulated labor, but which in fact is capital – It is most important, that these two ideas should be kept distinct; because labor and capital, are, if I may so express myself, in constant opposition to each other. The employment and the rewards of labour depending upon the amount of capital”⁶². Even the idea of production factors set in motion by agents already emerged⁶³.

⁵⁸ Letter from McCulloch to Ricardo, 24 August 1823, *ib.* p. 369.

⁵⁹ In this passage, McCulloch echoes what Ricardo wrote to him on March 29, 1820, in response to McCulloch's struggle with this distinction between gross and net produce associated with circulating and fixed capital. Ricardo then wrote: “The employment of machinery I think never diminishes the demand for labour – it is never a cause of a fall in the price of labour, but the effect of its rise”, *Letters 1819-June 1821*, Volume VIII of ‘The Works and Correspondence of David Ricardo’, ed. by P. Sraffa, Cambridge 1951 (to be referred to as *Letters VIII*) p. 171. See also Sraffa's *Introduction*, Volume I, p. lviii.

⁶⁰ Letter from McCulloch to Ricardo, 5 June 1821. *Letters VIII*, p. 382-383.

⁶¹ *ib.* p. 384.

⁶² Letter from Trower to Ricardo, 3 September 1823, *Letters IX*, p. 383-384.

⁶³ Letter from McCulloch to Ricardo, 11 August 1823, *ib.* p. 342-343.

And so it is that a new theory, the neoclassical theory, already arises in the correspondence with Ricardo, still based on Ricardo's principle that the least profitable production conditions determine wages and prices. Looking at all sectors of an economy and all machinery and other fixed capital that these sectors may have been using already for many years, the (uniform) wages are determined by their least productive and often oldest machinery, in conjunction with a price formation of their commodities so that their marginal costs are equal to their marginal revenues. If these wages are paid to all labourers, they determine the wage-share in the distribution of the whole product of labour within the economy. According to the neoclassical theory the highest profits result by equalizing marginal costs and marginal revenues⁶⁴. But a crucial question is whether sectors or firms which strive for profit maximization by keeping their machinery in operation as long as the revenues of the oldest machinery are precisely enough to pay the wages of the required labourers, also succeed in producing most efficiently?

Before going into this matter it should be noted first that the accumulation of capital per labourer has been accompanied by a much larger increase in the production per labourer. In the non-farm economy of the United States, for instance, the production per man hour approximately doubled over the period 1909-1949. According to Solow "about one-eighth of the total increase is traceable to increased capital per man hour, and the remaining seven-eighth to technical change"⁶⁵. Moreover, he commented on this technical change: "Obviously much, perhaps all, innovation must be embodied in new plant and equipment to be realized at all"⁶⁶.

So, investment-driven technical change became a major research topic in the broad development of the neoclassical theory, characterized by vintages of machinery that, due to technical progress, constantly require less labour in the year of their instalment compared to machinery installed a year earlier. In addition to an ever-lower labour intensity (α , every year diminishing with factor μ), new machinery can also lead to a changing production, or a changing capital/output ratio (κ , every year changing with factor λ). Furthermore, the development of feasible production depends on the annual physical depreciation (installed machinery diminishes every year with factor δ). In view of the observed wages and prices, together with the annual investments and labour supply, the technical parameters of the feasible production set (α , μ , κ , λ and δ) can be estimated in such a way that the observed production nicely fits within the feasible production set, while the estimated growth rates for wages, prices, investments and labour supply as much as possible correspond with the observed growth rates. The resulting steady state economy asks for savings that are equal to the investments. The required savings determine a saving rate σ , which enables to determine the real wages.

In fact, such a steady state economy corresponds well with the well-known Solow growth model. If the set of feasible production remains unchanged Solow rightly pointed out that "if there are two initially identical economies and one of them succeeds in consuming less of its output than the other, then after some lapse of time the return on investment will be lower and the real wages higher in the

⁶⁴ In this presentation of the neoclassical theory, it suffices to focus on the equality between marginal costs and marginal revenues in explaining the income distribution between wages and profits. I would also like to comment on how the relationship between capital and labour responds to changes in this distribution, but here I confine myself to Ricardo's expectation that wages would show a tendency to rise as a result of the increasing difficulty to produce food, with as a consequence "a tendency to determine the saved capital in a greater proportion than before to the employment of machinery. Machinery and labour are in constant competition, and the former can frequently not be employed until labour rises", *Principles*, p. 395. We have to amend this (rather neoclassical) statement of Ricardo as you will see later.

⁶⁵ R. Solow, *Technical Change and the Aggregate Production Function*, *The Review of Economics and Statistics*, Vol. 39, No. 3 (Aug., 1957), p.316.

⁶⁶ *ib.* p. 316.

high-saving economy than in the low-saving economy”⁶⁷. As savings and real wage increase, the age of the oldest machinery in operation decreases, until the accumulation of capital enables a steady state in which consumption reaches a maximum size. Within the existing set of feasible production higher investments than determined by the Golden Rule of Accumulation would be at the expense of possible consumption.

Today, many models use hypothetical households that intertemporal optimize consumption and savings, so that the Golden Rule of Accumulation is immediately met. But such households do not exist in reality. To get grip on reality, it is rather important to see that a vintage model just has a most profitable lifetime in addition to the economic lifetime of machinery which is determined by the equality between marginal costs and marginal revenues. This most profitable lifetime appears independent of wages and prices, thus independent of the income distribution: it is only determined by both the technical parameters that describe the set of the feasible production and the growth rate of the investments. This model⁶⁸ thus supports the correctness of the first principle of Ricardo. But there is more.

If there are many firms in a sector that keep their machinery in operation as long as they are profitable in view of the prevailing wages, it is almost always possible that one or more firms start to produce more efficiently. It is then of the utmost importance to have the solution to Ricardo's search for a measurement of technical change that is independent of changes in the income distribution. By this measurement we are able to prove that such firms actually exist. It will prove that oligopolistic competition is not necessarily a result of market imperfection, but on the contrary frequently the natural consequence of firms that start to produce more efficiently than their competing firms that remain producing according to the neoclassical theory. It will also prove that the real world is far more complex than the neoclassical theory suggests, even in its most elaborate form.

Let us assume that the measurement of technical change proves indeed the existence of more efficient firms that are gaining market power over competing firms that lag behind in efficiency although they may still think to make the highest possible profit. These more efficient firms do not necessarily have to be innovative firms. Entrepreneurial capabilities can also prove to be present by replacing machinery while it, within the existing technology and given the prevailing wages and prices, still generate profit. An earlier replacement may nevertheless result in more efficient production with, on balance, less use of direct and indirect labour⁶⁹. However, firms need entrepreneurial capabilities to see that they can produce their commodities more efficiently. Moreover, such firms can enforce the savings they need and, under certain circumstances, even withdraw labour from the production of consumer commodities.

The market power of more efficient firms over firms that continue to produce according to the neoclassical theory and which, according to Ricardo's principles, still determine the prevailing wages and prices, is first and foremost reflected in more profit. The more efficient firms can use their relatively higher profits to push the boundaries of the production technology by applying new innovations, or by attracting better-qualified and also by better-paid labour that may also help to

⁶⁷ R. Solow, *Capital theory and the rate of return*, Amsterdam, 1963.

⁶⁸ Your writer eagerly refers to the paper mentioned in footnote 5.

⁶⁹ The revised version of the paper mentioned in footnote 5 shows that the actual development of investments can be reasonably well explained on the basis of coefficients of a model that apply continuously for the entire period 1960-2018. This good explanation is possible on the basis of an estimated market share of 'Schumpeterian' firms, which has increased sharply in the US and Germany in the most recent period, while competitiveness in France and the UK has clearly declined.

push the boundaries of the production technology, or last but not least by increasing their production by lowering their prices at the expense of the competing neoclassical firms. These last firms can only respond by either reducing their wages or scrapping their machinery earlier. Their replacement investments may also become at stake due to a lack of savings that are increasingly being seized by the more efficient firms. Nevertheless, account must also be taken of the possibility that firms that for some time produced more efficiently than their competitors would fall back into a neoclassical production pattern.

Reality forces us to acknowledge that consumers are not the ones who, with their saving behaviour, trigger an economic development that is moving towards production according to the Golden Rule. It is precisely the firms with entrepreneurial capabilities that are responsible for this. These firms also ensure that the boundaries of production technology are constantly being pushed, so that the Golden Rule of Accumulation is also constantly brought to a higher level. For economic development, the role of firms whose entrepreneurial capabilities enable them to achieve more efficient production is crucial. And that those firms exist can be proven by measuring the technical change in the labour worked up in commodities.

But the history of economic development also gives many indications that these more efficient firms exist. Many industrial sectors that were initially characterized by many competing firms were gradually dominated by a few firms that grew larger compared to their other competitors. The oligopolistic competition as a result of more efficient production of some firms in comparison with firms that remain producing in accordance with the neoclassical theory, introduces many complexities. For example, the distribution of income between wages and profits is no longer determined by machinery with a marginal revenue that is equal to the marginal costs as soon as more efficient firms start paying relatively higher wages. Oligopolistic competition makes the income distribution more or less undetermined.

More importantly, oligopolistic competition does not stop at borders: for example, the more efficient firms in the US can also exercise market power over their competitors in Europe. Particularly in less favourable economic times, competition may become more intense and go hand in hand with relative price decreases that benefit the position of more efficient firms. In countries where production is essentially in line with the neoclassical theory, unemployment may arise, while policies to combat unemployment may not necessarily be successful. Subsidies or wage moderation may only provide temporary relief. By trying to avoid a switch to more efficient production, these policies may ultimately damage an economic development aimed at an optimal level of consumption and may instead contribute to long-lasting unemployment.

But there may also be economically less favourable circumstances in which the more efficient firms do not seek intensified competition by lower prices, but use their extra profit precisely to prepare themselves for renewed growth once the circumstances have changed fundamentally. Such less favourable circumstances can also be pre-eminently the result of shifting boundaries of the production technology that make it possible to solve fundamental problems, but not after politicians have committed themselves to possible solutions whether or not in an international context. At present, a necessary but not yet agreed world-wide transition to a truly sustainable economic development appears to be an obstacle to the necessary human activity for the time being.

Our present problems resemble those of the past when two cities were separated by a fast-flowing river and therefore could hardly benefit from each other's comparative advantages. The rather disconnected economies of both cities could start thinking of integration as soon the construction of a bridge became within the boundaries of the production technology. Firms on either side of the river would prepare themselves for the phase that starts after the bridge is built. Awaiting the construction of the bridge that politics should arrange with possibly a long period of preparation, the investment activity of those firms will initially decrease and increase sharply once the bridge is almost finished. The labour that is released by the temporarily less investment can even help to actually build the bridge.

In special times, even firms with entrepreneurial capabilities need clear directives, prescribed by politics without any doubt about their future applicability, before they can help tackle sustainability problems fundamentally. In the meantime, they will wait until the desired playing field has been created.

POSTSCRIPT

A final quote in which David Ricardo, as it were, anticipates the solution of the problem of value, I do not want to withhold the reader. He starts his chapter *Value and Riches, their Distinctive Properties*⁷⁰ as follows:

“A man is rich or poor,” says Adam Smith, “according to the degree in which he can afford to enjoy the necessaries, conveniences, and amusements of human life.”

Value, then, essentially differs from riches, for value depends not on abundance, but on the difficulty or facility of production. The labour of a million of men in manufactures, will always produce the same value, but will not always produce the same riches. By the invention of machinery, by the improvements in skill, by a better division of labour, or by the discovery of new markets, where more advantageous exchanges may be made, a million of men may produce double, or treble the amount of riches, of “necessaries, conveniences, and amusements,” in one state of society, that they could produce in another, but they will not on that account add any thing to value; for every thing rises or falls in value, in proportion to the facility or difficulty of producing it, or, in other words, in proportion to the quantity of labour employed on its production.

With the solution of the problem of value at hand we are able to see whether human beings are capable of producing the riches with which they wish to surround themselves as efficiently as possible, which means with as little human labour as possible. In determining whether and where the production of a society anywhere in the world has become more efficient, Ricardo makes no distinction between the labour of different human beings. Regardless of their skills, experience, education or gender, Ricardo considers the labour or labour hours of all human beings within a society in determining technical change to be equal. In measuring the technical change of commodities the labour contribution of each individual to their production is taken into account in the same way.

⁷⁰ *Principles*, Chapter XX, p. 273.

History shows that firms have proven to be powerful drivers of a production that has become more and more efficient over time, even though societies in which they operate impose rules that they must comply with. As economic development progressed, it became furthermore increasingly clear that producing the desired riches also means producing it without undesired consequences. This requires even stricter rules to ensure that production takes place in a sustainable manner that does not affect the production possibilities in the future. The solution to what is frequently called Ricardo's labour theory of value helps achieve that goal as efficiently as possible, although it is no longer a theory: the solution provides factual information about the actual changes in worked up labour.