Ricardo on Machinery: A Textual Analysis

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Abstract

Modern production theory (Kurz and Salvadori, 1995) is utilized to provide a textual analysis of the famous chapter "On Machinery" added by Ricardo in the third edition of his *Principles* and to reconstruct the examples that are reported there. Two sets of assumptions that rationalize the basic example presented by Ricardo are identified: a) the innovation concerns a non-basic commodity; b) the innovation concerns an agricultural commodity and it does not change the technology applied on the marginal land, which is still marginal after the innovation. Ricardo was aware of these two facts and he seems to have used the latter of the two in his initial example. In effect, the example holds perfectly well if it is assumed that the new machine is specific to a quality of land that is marginal neither in the pre-innovation nor in the post-innovation economy. When the innovation is introduced in the production of an industrial commodity (cloth) that is used by the workers, as in the second example discussed by Ricardo, the rate of profits, and therefore the rate of growth, cannot be the same in the pre-innovation and in the post-innovation economy, unless the innovation is introduced in a switch-point between the technique employed prior to the innovation and that used after the innovation. This is too strong an assumption and can be of some interest only if it provides information about events that occur in the vicinity of a switch point. This "continuity" assumption is what Ricardo seems to have used as the basis for discussion in his second example.

1. Introduction

The chapter "On Machinery" that Ricardo added in the third edition of his *Principles*[2] has attracted the attention of many economists: Whewell (1831), Wicksell ([1923] 1981), Hayek (1931, 1942, 1969), Kaldor (1932), Stigler (1952), Hicks (1969), Hollander (1971), Barkai (1986), Kurz (1984, 2010, see also Jeck and Kurz, 1983), Samuelson (1988, 1989, 1994), Davis (1989), Gehrke (2003, 2010) among many others. In many of these contributions the reader can find examples in which substitution of machinery for human labour is injurious to the interests of the workers. However, the

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[2] It is remarkable that Ricardo omitted to integrate the findings of the new chapter into his rent theory; see Gehrke 2015.

reader finds no reconstruction of the examples that Ricardo elaborated in Chapter XXXI of the *Principles* (exceptions are Barkai, 1986 and Gehrke, 2010): reconstructing such examples means determining a set of assumptions that Ricardo did not state explicitly but that must hold in order for the examples to work. This is the procedure we will adopt in this paper. More generally, in none of the mentioned contributions do we find a textual analysis of the chapter with a reconstruction of the examples provided by Ricardo on the basis of the modern production theory (Kurz and Salvadori, 1995), whereas in this paper we try to provide precisely such a reconstruction. The aim is *not* to prove that examples can be built which yield the same effects as Ricardo found (or believed he had found). The aim is to prove that *exactly his examples* can be reconstructed. We will thereby determine a set of assumptions that Ricardo did not state explicitly. Of course we cannot mantain either that these are the very assumptions Ricardo had in mind or that no other set of assumptions may accomodate the same task. On the contrary, in one case we indicate two different sets of assumptions.

Ricardo's chapter "On Machinery" can be divided into three parts. In the first part, Ricardo outlines the arguments he intended to put forward in the chapter, namely, that "substitution of machinery for human labour, is often very injurious to the interests of the class of labourers" (Works I: 388). Ricardo states his case very cautiously since he was aware that what he planned to deliver in the chapter was not popular among economists of the time. In fact he himself had held a different opinion in the past: in the *Essay on Profits* he had likened the effects of a low money price of corn to the outcome of improved machinery, "which it is now no longer questioned, has a decided tendency to raise the real wages of labour" (Works IV: 35). In the second part Ricardo produces a numerical example which is designed to illustrate the main argument of the paper. In the third part he comments on the example and also provides ideas of other, less simple, examples that could be built. He also argues that consumption by capitalists and landlords may play a role on how and whether the substitution of machinery for labour is injurious to the interests of labourers. Finally, he outlines his conclusions. We follow Ricardo in the analysis of his example and of his comments upon it.

2. Ricardo's example

It is helpful to transcribe the whole text with passages numbered for convenient references.

> [1] A capitalist we will suppose employs a capital of the value of 20,000*l*. and that [2] he carries on the joint business of a farmer, and a manufacturer of necessaries. [3] We will further suppose, that 7000*l*. of this capital is invested in fixed capital, viz. in buildings, implements, &c. &c. and that [4] the remaining 13,000*l*. is employed as

circulating capital in the support of labour. [5] Let us suppose, too, that profits are 10 per cent., and consequently that the capitalist's capital is every year put into its original state of efficiency, and yields a profit of 2000*l.*

[6] Each year the capitalist begins his operations, by having food and necessaries in his possession of the value of 13,000*l.*, all of which he sells in the course of the year to his own workmen for that sum of money, and, during the same period, he pays them the like amount of money for wages: at the end of the year they replace in his possession food and necessaries of the value of 15,000*l.*, 2000*l.* of which he consumes himself, or disposes of as may best suit his pleasure and gratification. As far as these products are concerned, the gross produce for that year is 15,000*l.*, and the net produce 2000*l.* [7] 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 sum of 13,000*l.* in 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?

[8] While the machine was being made, only one-half of the usual quantity of food and necessaries would be obtained, and they would be only one-half the value of the quantity which was produced before. The machine would be worth 7500*l.*, and the food and necessaries 7500*l.*, and, therefore, the capital of the capitalist would be as great as before; for he would have besides these two values, his fixed capital worth 7000*l.*, making in the whole 20,000*l.* capital, and 2000*l.* profit. [9] After deducting this latter sum for his own expenses, he would have a no greater circulating capital than 5500*l.* with which to carry on his subsequent operations; and, therefore, his means of employing labour, would be reduced in the proportion of 13,000*l.* to 5500*l.*, and, consequently, all the labour which was before employed by 7500*l.*, would become redundant.

[10] The reduced quantity of labour which the capitalist can employ, must, indeed, with the assistance of the machine, and after deductions for its repairs, produce a value equal to 7500*l.*, it must replace the circulating capital with a profit of 2000*l.* on the whole capital; but if this be done, if the net income be not diminished, of what importance is it to the capitalist, whether the gross income be of the value of 3000*l.*, of 10,000*l.*, or of 15,000*l.*? (Works I: 388-9)

Passages 1-6 refer clearly to a long-period position in which the rate of profits is 10%, but the economy is stationary (see in particular passage 5 and 6). Let us call r_{min} the rate of profits of the

stationary economy; hence $r_{\min} = 0.1$. In this economy only the production of a farmer producing necessary goods is analyzed (see passage 2). Let us refer to the commodity produced by the farmer as corn; corn is the necessary good and therefore it is the commodity consumed by workers, Since the capitalist is a farmer, landlords also exist. However payment of rent is not mentioned: one may surmise that rent is paid in corn and detracted by the product. Production is carried out with land, fixed capital (passage 3) and circulating capital, which consists of wages only (passage 4), as in Pasinetti's Ricardian model (Pasinetti, 1960). Fixed capital is everlasting (passage 5). In modern theory a long-period described by Ricardo in passages 1-6 can be stated as follows.

There are three processes to produce corn, each with a different quality of land, labour and fixed capital that is everlasting and one process to produce the fixed capital. The input-output coefficients are represented in Table 1. There exist 260 units of land of quality 1, 500 units of land of quality 2, and 200 units of land of quality 3. The wage rate equals 1 unit of corn. The fixed capital/labour ratio equals 7/13 in all processes: it is therefore possible to consider relative prices as independent of distribution. In effect Ricardo measures all commodities in sterling without attention to changes in prices as a function of the rate of profits, which is possible only if the labour theory of value holds. For the moment we will assume that corn is the commodity consumed by all classes.

Processes	fixed capital	new machine	labour	land 1	land 2	land 3		corn	fixed capital	new machine
(1)	35		65	13				117.5	35	
(2)	35		65		10			80	35	
(3)	35		65			65		75	35	
(4)	35		65						110	

Table 1. The input-output patterns of the first example: the pre-innovation technology

If all qualities of land are cultivated, prices are determined by the equations

$$\left(35 p_{fc} + 65\right)\left(1+r\right) + 13\rho_1 = 117.5 + 35 p_{fc}$$

$$\left(35 p_{fc} + 65\right)\left(1+r\right) + 10\rho_2 = 80 + 35 p_{fc}$$

$$\left(35 p_{fc} + 65\right)\left(1+r\right) = 75 + 35 p_{fc}$$

$$\left(35 p_{fc} + 65\right)\left(1+r\right) = 110 p_{fc}$$

The last two equations determine $p_{fc} = 1$ and $r = 0.1$. The first two equations determine $13\rho_1 = 42.5$ and $\rho_2 = 0.5$. If the capital to be invested is 20000, as in Ricardo's example, then all

lands are cultivated, the intensities of operation of the processes are $x_1 = 20$, $x_2 = 50$, $x_4 = 0$, and x_3 is determined by the equation

$$100(x_1 + x_2 + x_3) = 20000 ,$$

that is $x_3 = 200 - 20 - 50 = 130$. Hence we have, as in Ricardo's example, that fixed capital equals 7000, the profit rate is 0.1, but now we have made rents explicit. Employment equals 13000. Since fixed capital is everlasting, the fact that $x_4 = 0$ means the economy is stationary. Nevertheless process (4) contributes to determining prices.

Let us turn to Ricardo's wording. Passage 7-9 clearly refers to a transition from one long-period position to another. The transition lasts one year only. In this year half of the capital is employed in the production of a machine; the other half of capital is used for the production of corn (passage 7). The rate of profits is unchanged, which may be read as meaning that the marginal land does not change. The value of the machine is equal to cost plus profit at the rate of 0.1. This may in turn be read as meaning that production of the machine does not involve the use of land. The value of the corn produced does not involve rents either, but this can be interpreted, as before, in the sense that rent has been deducted and paid in corn (passage 8). At the end of the transition year the capitalist has the new machine, but the amount of corn he can use as circulating capital is strongly reduced, even if the quantity of total capital is the same as above. Moreover with the new machine and the reduced amount of circulating capital the farmer can produce the same or a greater amount of corn (passage 9). Passage 10 describes the long-period position resulting from the innovation; the economy is still stationary since the rate of profits is still 0.1. This implies that the marginal land is unchanged and the process to produce corn on it is also unchanged. However, the capitalist is *not* indifferent between introducing the new machine or not. If the machine is specific to a quality of land different from the marginal land that is inframarginal after the innovation, then the capitalist recognizes, before the introduction, that he can produce a larger amount of corn, and hence reap an extraprofit, but after the introduction the larger amount of corn is appropriated by the landlords, since the rate of profits is determined by the technology used on the marginal land. In modern theory the transition period described by Ricardo in passages 7-8 and the long-period position consequent upon the innovation described by Ricardo in passages 9-10 could be stated as follows.

During the transition processes (1)-(3) are still used and process (5) is also used, whereas after the transition period the processes (1), (3), and (6) are used, where processes (5) and (6) are represented in Table 2.

Processes	fixed capital	new machine	labour	land 1	land 2	land 3		corn	fixed capital	new machine
(5)	3500		6500						3500	1
(6)	$\dfrac{52500}{13}$	1			500			$\dfrac{115750}{13}+A$	$\dfrac{52500}{13}$	1

Table 2. The input-output patterns of the first example: the innovation technology

It is easily recognized that at the prices before innovation $p_M = 7500$ and the process (6) produces extraprofit since $A > 0$:

$$\left(\frac{52500}{13}+p_M\right)1.1+500\rho_2 < \frac{115750}{13}+A+\frac{52500}{13} \Leftrightarrow A>0$$

However, as soon as the innovation is introduced, the rent on land of quality 2 becomes $\rho_2 = (250+A)/500$ and extraprofit is appropriated by landlords.[3] If the capital to be invested is 20000, as in the example of Ricardo, then all lands are cultivated, the intensities of operation of the processes are $x_1 = 20$, $x_2 = 0$, $x_4 = 0$, $x_5 = 0$, $x_6 = 1$, and x_3 is determined by the equation

$$100\left(x_1+x_3\right)+\frac{52500}{13}+p_M = 20000$$

that is $x_3 = \frac{840}{13}$. Hence we have, as in Ricardo's example, that fixed capital equals 7000, the profit rate is 0.1 and employment equals 5500.

In the transition year the intensities of operation of the processes are $x_1 = 20$, $x_2 = 50$, $x_4 = 0$, $x_5 = 1$, $x_6 = 0$ and x_3 is determined by the equation

$$100\left(x_1+x_2+x_3+100x_5\right) = 20000$$

that is, $x_3 = 30$. Hence we have, as in Ricardo's example, that fixed capital equals 7000, the profit rate is 0.1 and employment equals 13000.[4]

We have chosen the available amounts of land in such a way that the marginal land is land of quality 3 both in the long-period position consequent upon the innovation and in the transition year. Moreover, in our example the new machine is specific to land of quality 2; of course we could have

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[3]   Note that the growth rate is unchanged also because it is assumed that landlords do not invest part of their income.

[4]   One may wonder that capital is 20000 before the innovation, after the innovation, and during transition because the available amount of capital is given. But this is not so: capital is constant over time since the growth rate is nought, and this is so since the rate of profit is at the level of the stationary state.

chosen a numerical example such that it was specific to land of quality 1 or to a land which is supramarginal before the innovation and inframarginal after the innovation.

3. Ricardo's first comment

Ricardo's first comment on the example is highly technical and is related to his change of opinion mentioned in the first part of his chapter. From a technical point of view the novelty of the chapter is as follows:

> In this case, then, although the net produce will not be diminished in value, although its power of purchasing commodities may be greatly increased, the gross produce will have fallen from a value of 15,000*l*. to a value of 7500*l*., and as the power of supporting a population, and employing labour, depends always on the gross produce of a nation, and not on its net produce, 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. (pp. 389-90)

Despite the fact that technical change may increase profit plus rent (the net produce) it may at the same time decrease the resources available for employing workers (the gross produce minus the net produce). A new technique is introduced if it generates extraprofit at the prices holding before the innovation. Ricardo thus surmised that rents plus profit must increase whereas previously he was convinced that wages cannot decrease. As a matter of fact the reswitching debate proved that even if technology is characterized by single production (and therefore land and fixed capital are *not* among the inputs and the outputs) at a given wage rate, the changes consequent upon technical change may include a rise in capital/income ratio. If this is the case and the capital is constant (or slightly increased), then income is reduced and since profit increases, the wage bill is decreased and, therefore, employment is reduced. Of course this cannot hold if technology is such that the labour theory of value prevails. Ricardo's examples show that even in this case employment may be reduced if fixed capital is introduced.

The example shows clearly that the 'substitution of machinery for human labour' *may be* 'injurious to the interests of the class of labourers'. The fact that a number of strong assumptions have been needed to bring home the result does not mean that such an event is rare. The assumptions were mainly invoked to isolate the problem and to allow crystal clear recognition of its occurrence. If, for example, the economy had been growing, the effects of the innovation on growth could not have been sterilized. Similarly for the assumption, implicit in Ricardo, that all classes consume only corn. In his analysis of the example Ricardo removes some of these assumptions and we will follow him.

4. Landlords' consumption

What happens if we introduce the assumption that landlords, as in Pasinetti's model (Pasinetti, 1960), consume an industrial commodity? Let us follow Pasinetti and call this commodity gold, with the assumption that a units of labour produce one unit of gold. Then the price of gold is $p_2 = wa(1+r) = 1.1a$. In the pre-innovation economy as well as in the transition economy the landlords obtain a total rent $R = 260\rho_1 + 500\rho_2 = 850 + 250 = 1100$. As a consequence the amount of gold produced is $\frac{1000}{a}$ and employment in the gold sector equals 1000. In the post-innovation economy $R = 1100 + A$. Hence the employment in the gold sector is increased by $A/1.1$. Thus if $A \geq 8250$, then total employment is increased in the post-innovation economy.

Ricardo is very aware of the relevance of expenditures of different classes:

> Independently of the consideration of the discovery and use of machinery, to which our attention has been just directed, the labouring class have no small interest in the manner in which the net income of the country is expended, although it should, in all cases, be expended for the gratification and enjoyments of those who are fairly entitled to it. (p. 392)

In particular, Ricardo considers the consumption of the services of "menial servants" as the most advantageous for the working class:[5]

> If a landlord, or a capitalist, expends his revenue in the manner of an ancient baron, in the support of a great number of retainers, or menial servants, he will give

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[5]   Ricardo extends his analysis beyond private consumption to public consumption.
> In the same manner, a country engaged in war, and which is under the necessity of maintaining large fleets and armies, employs a great many more men than will be employed when the war terminates, and the annual expenses which it brings with it, cease. (p. 393)

And shortly afterwards,
> At the termination of the war, when part of my revenue reverts [from tax expenses] to me, and is employed as before in the purchase of wine, furniture, or other luxuries, the population which it before supported, and which the war called into existence, will become redundant, and by its effect on the rest of the population, and its competition with it for employment, will sink the value of wages, and very materially deteriorate the condition of the labouring classes. (p. 394)

Ricardo probably witnessed all this: from 1815 to 1821, with Napoleon in Saint Helena, the British army and the fleet were reduced and the number of the poor increased.

employment to much more labour, than if he expended it on fine clothes, or costly furniture; on carriages, on horses, or in the purchase of any other luxuries.

In both cases the net revenue would be the same, and so would be the gross revenue, but the former would be realised in different commodities. If my revenue were 10,000*l.,* the same quantity nearly of productive labour would be employed, whether I realised it in fine clothes and costly furniture, &c. &c. or in a quantity of food and clothing of the same value. If, however, I realised my revenue in the first set of commodities, no more labour would be *consequently* employed:—I should enjoy my furniture and my clothes, and there would be an end of them; but if I realised my revenue in food and clothing, and my desire was to employ menial servants, all those whom I could so employ with my revenue of 10,000*l.,* or with the food and clothing which it would purchase, would be to be added to the former demand for labourers, and this addition would take place only because I chose this mode of expending my revenue. As the labourers, then, are interested in the demand for labour, they must naturally desire that as much of the revenue as possible should be diverted from expenditure on luxuries, to be expended in the support of menial servants. (p. 393)

Note that if the industrial commodity consumed by landlords (gold in Pasinetti's terminology) is produced by using labour and fixed capital, then producers of corn can partially move their capital from corn production on land of quality 3 to gold production; employment could thus be lower in the post innovation economy even if $A \geq 8250$. This is not possible when gold is produced by labour alone since if producers of corn partially moved their capital from corn production to gold production, then some fixed capital would not be used; accordingly, its price would fall. Obviously this movement of capital cannot be so large that land of quality 2 becomes marginal, because in this case the demand for gold would fall. Hence in the assumption that 7 units of fixed capital and 13 units of labour are needed to produce 1 unit of gold, total employment is certainly increased in the post innovation economy only if A > 165000.

5. The industry of the innovator

Ricardo argues that unemployment may also be generated by technical change in less specific cases and in particular if the innovation is introduced in an industry not producing corn; as an example, a clothier is mentioned.

The case which I have supposed, is the most simple that I could select; but it would make no difference in the result, if we supposed that the machinery was applied to

> the trade of any manufacturer, — that of a clothier, for example, or of a
>
> cotton manufacturer. (pp. 390-91)

But what kind of cloth does the clothier produce? Let us analyze first the case in which the cloth produced by the clothier is a luxury good, consumed by the landlords. (In the following we continue to use gold for landlords' consumption, instead of cloth.)

Suppose that the landlords consume gold and that the new machine is used in the production of gold. Note that only the producers of corn can divert workers from the job in which they are employed before the innovation, shifting them to the production of the new machine, but it is convenient to do so since an extraprofit can be obtained (at the prices holding before the innovation). The new machine is still produced by process (5), whereas the processes used to produce gold are represented in Table 3.

Processes	fixed capital	new machine	labour	land 1	land 2	land 3		gold	fixed capital	new machine
(7)			a					1		
(8)	3500	1						B	3500	1

Table 3. The input-output patterns of the second example

The transition period is the same as above. After the introduction of the new machine, the price of production of gold is reduced, the extraprofit (in terms of production prices) vanishes, and the normal rate of profits is determined in agriculture. Nevertheless the economy has obtained a long-period position since

$$3500r + rp_M = 260\rho_1 + 500\rho_2$$

The price of gold is determined by the equation

$$3500(1+r) + (1+r)p_M = 3500 + p_M + Bp_2$$

where $B > (3500r + p_M r)/[(1+r)a] = 1000/a$. Employment in the transition year is obviously unchanged. Employment in corn production in the long-period position after the innovation equals the employment in corn production in the transition period, namely, one half of the employment in corn production in the long-period position before the innovation. Moreover the circulating capital employed in gold production has vanished.

If the clothier produces cloth consumed by the working class (or used in the production of necessaries), this requires a complete change in the example since the rate of profits is then determined not only by the corn industry, but by the cloth industry as well. If we read Ricardo's

wording carefully, it is clear that he is considering a case in which cloth is used in the production of clothing for workers, i.e. a basic commodity.

> If [the machine is introduced] in the trade of a clothier, less cloth would be produced after the introduction of machinery; for a part of that quantity which is disposed of for the purpose of paying a large body of workmen, would not be required by their employer. In consequence of using the machine, it would be necessary for him to reproduce a value, only equal to the value consumed, together with the profits on the whole capital. 7500*l.* might do this as effectually as 15,000*l.* did before, the case differing in no respect from the former instance. (p. 391)

Ricardo, however, does not take into account a change in the rate of profits. Nevertheless, if a new process is introduced in the production of a basic commodity and the wage rate is given, then the rate of profits must increase *unless* the new process is equivalent to the old one and therefore it may or may not be introduced. This is actually what Ricardo seems to have in mind since he considers only movements in quantities and not in prices.

> It may be said, however, that the demand for cloth would be as great as before, and it may be asked from whence would this supply come? But by whom would the cloth be demanded? By the farmers and the other producers of necessaries, who employed their capitals in producing these necessaries as a means of obtaining cloth: they gave corn and necessaries to the clothier for cloth, and he bestowed them on his workmen for the cloth which their work afforded him.
>
> This trade would now cease; the clothier would not want the food and clothing, having fewer men to employ and having less cloth to dispose of. (p. 391)

In short, the clothier is now demanding corn only to cover his own consumption of corn and not that of his workers. But since the new process is equivalent to the old one some other producer will produce cloth with the old process: nevertheless the amount of employment has been reduced.

> The farmers and others, who only produced necessaries as means to an end, could no longer obtain cloth by such an application of their capitals, and, therefore, they would either themselves employ their capitals in producing cloth, or would lend them to others, in order that the commodity really wanted might be furnished; and that for which no one had the means of paying, or for which there was no demand, might cease to be produced. This, then, leads us to the same result; the demand for labour would diminish, and the commodities necessary to the support of labour would not be produced in the same abundance. (p. 391)

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However the assumption of a new process equivalent to the old one is too restrictive to be of interest. Ricardo probably wanted to suggest that in more general cases, in which the new process is better than the old one at the old prices, but close to being equivalent, then the rate of profits increases above $r_{min} = 0.1$, and therefore the growth rate becomes positive. Neverthless after a while the stationary state is obtained again (in our example we need either a process producing corn using quality of land 4 or a process producing corn that uses one of the qualities of land 1, 2, or 3 more intensively); moreover, the increment of capital may not be large enough to compensate for the loss of employment consequent upon use of the machine.[6] Even if the example loses the simplicity that makes it so appealing, there is no reason to believe that employment cannot be reduced because of an innovation.

In order to simplify the argument let us assume that corn and cloth are consumed in a fixed proportion of one-to-one by all classes. Ricardo's example then can be represented by using processes described in Table 4. Process (9) may use also land, but since we are considering a switch point we do not need to consider land and rent explicitly (recall that rent is never mentioned by Ricardo in chapter XXXI).

Processes	fixed capital	new machine	labour	land		corn	fixed capital	cloth	new machine
(9)	35		65			75	35		
(10)	35		65				35	75	
(11)	35		65				110		
(12)	3500		6500				3500		1
(13)	$\frac{52500}{13}$	1					$\frac{52500}{13}$	$\frac{15000}{13}$	1

Table 4. The input-output patterns of the third example

Assuming that the wage basket contains ½ unit of corn and ½ unit of cloth, relative prices and the rate of profits are determined by the following four equations:

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[6]   Obviously this could be a possible interpretation for the example of section 2 above as well. This interpretation would also explain why Ricardo did not calculate rent. However, the interpretation we have given in section 2 is much more appealing since no recourse to approximation is required. Moreover, in the analysis of the example with cloth consumed by the workers Ricardo refers to the need for the producer of corn to use the old process in order to produce cloth (either directly or by hiring out the process to others); see below. The fact that he does not mention this in the analysis of the first example suggests that he followed a strategy similar to the one we have proposed (unchanged marginal land and unchanged technology used on the marginal land).

$$75p_c + 35p_{fc} = (1+r)\left(35p_{fc} + \frac{1}{2}65p_c + \frac{1}{2}65p_{cl}\right).$$

$$75p_{cl} + 35p_{fc} = (1+r)\left(35p_{fc} + \frac{1}{2}65p_c + \frac{1}{2}65p_{cl}\right).$$

$$110p_{fc} = (1+r)\left(35p_{fc} + \frac{1}{2}65p_c + \frac{1}{2}65p_{cl}\right).$$

$$p_M + 3500p_{fc} = (1+r)\left(3500p_{fc} + 6500p_c\right).$$

Hence $1 = p_c = p_{fc} = p_{cl}$, $(1+r) = 1,1$. $p_M = 7500$.

Initially processes (11), (12) and (13) are not brought into operation even if they are cost-minimizing at the switch-point.

Assume the clothier uses capital of 20000. The operation intensity of process (10) is therefore 200. The clothier produces 15000 units of cloth of which he exchanges 7500 with the farmer, obtaining 7500 units of corn. He consumes 1000 units of corn and 1000 units of cloth and uses the remaining 6500 units of corn, together with 6500 units of cloth, to pay the workers' wages. The farmer then employs 6500 units of cloth and 6500 units of corn as wage bill. This means that the operation intensity of (9) is 200.[7] 15000 units of corn are produced, of which 1000 are consumed by the farmer himself, 7500 are sold to the clothier, and 6500 are given to workers as wages.

If in the transition year the clothier uses half of his workers and half of his fixed capital to produce the machine with process (12), in the subsequent year only 7500 units of cloth are produced by the clothier. This means that the farmer cannot operate process (9) at the pre-invention intensity of 200 in the transition year, so he has to produce cloth himself or he has to lend part of his capital to others, in order that cloth can be supplied. If the farmer produced 15000 units of corn, there would be an excess of corn (the part that cannot be sold to the clothier and the part that cannot be used as wages to produce corn since the complementary factor cloth is missing) and an excess of fixed capital. Ricardo's solutions seem to be the following: either (a) the farmer can anticipate the reduction in supply of cloth by the clothier, reduce the production of corn and produce some cloth directly using process (10); or (b) the farmer can anticipate the reduction in the supply of cloth, reduce the production of corn, and lend the capital thereby made available to others who produce cloth. In either manner, in the transition year only 11250 units of corn and 11250 units of cloth are produced since a quarter of the whole capital is now employed in the production of the machine. Since 2000 units of both goods are consumed by the capitalists, the wage bill after the transition year comprises 9250 units of corn and 9250 units of cloth.

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[7] Obviously if we distinguish the processes producing corn on lands of qualities 1, 2, and 3, respectively, rent rates on lands of quality 1 and 2 emerge and make the three processes equivalent for the corn producer.

After the transition year the production of corn is ¾ of the original production of 15000 (i.e. 11250 units) and the wage bill is reduced by 7500 units (from 26000 to 18500). The reallocation of the farmer's capital does not alter the employment generated by his capital, but the wage bill and, hence, total employment decrease by 7500 units because the clothier produces less cloth and employs less labour, since "it would be necessary for him to reproduce a value, only equal to the value consumed, together with the profit on the whole capital. 7500*l*. might do this as effectually as 15,000*l*. did before". As noted by Ricardo, this case "in no respect [differs] from the former instance", where the machine is introduced by the farmer.

6. A further example: a historical case

Ricardo considers it appropriate to refer to a historical example: the substitution of the labour performed by horses for human labour.

> There is one other case that should be noticed of the possibility of an increase in the
> amount of the net revenue of a country, and even of its gross revenue, with a
> diminution of demand for labour, and that is, when the labour of horses is substituted
> for that of man. If I employed one hundred men on my farm, and if I found that the
> food bestowed on fifty of those men, could be diverted to the support of horses, and
> afford me a greater return of raw produce, after allowing for the interest of the capital
> which the purchase of the horses would absorb, it would be advantageous to me to
> substitute the horses for the men, and I should accordingly do so; but this would not
> be for the interest of the men, and unless the income I obtained, was so much
> increased as to enable me to employ the men as well as the horses, it is evident that
> the population would become redundant, and the labourers' condition would sink in
> the general scale. (p. 394)

Now Ricardo can take advantage of the historical facts. Here instead of everlasting fixed capital, we still have fixed capital, but not everlasting. Nevertheless the results are similar. But Ricardo knows that in this case employment actually decreased for a while, but new work opportunities were created, although not in agriculture and such opportunities were not a consequence of the substitution of horses for men.

> It is evident he could not, under any circumstances, be employed in agriculture; but if
> the produce of the land were increased by the substitution of horses for men, he
> might be employed in manufactures, or as a menial servant. (pp. 394-5)

This historical example is also helpful in order to better understand the role of the assumption of the stationary state. It is certainly not necessary, but it allows a much clearer view of the phenomenon Ricardo seeks to analyse: in a growing economy the unemployment created by the introduction of machinery is absorbed by the growth of the economy, and the only adverse effect that can be detected is merely a temporary decline in growth for a while and some unemployment that could be considered frictional.

7. Saving and growth

The role of growth in Ricardo's examples is clearly stated by Ricardo himself.

> As, however, the power of saving from revenue to add to capital, must depend on the efficiency of the net revenue, to satisfy the wants of the capitalist, it could not fail to follow from the reduction in the price of commodities consequent on the introduction of machinery, that with the same wants he would have increased means of saving,—increased facility of transferring revenue into capital. But with every increase of capital he would employ more labourers; and, therefore, a portion of the people thrown out of work in the first instance, would be subsequently employed; and if the increased production, in consequence of the employment of the machine, was so great as to afford, in the shape of net produce, as great a quantity of food and necessaries as existed before in the form of gross produce, there would be the same ability to employ the whole population, and, therefore, there would not necessarily be any redundancy of people. (p. 390)

Ricardo seems to support a view in which saving is a rather complex function in which consumption by individual capitalists plays a role. The issue is also dealt with in Chapter VII, on foreign trade, where we read the following.

> There are two ways in which capital may be accumulated: it may be saved either in consequence of increased revenue, or of diminished consumption. If my profits are raised from 1000*l.* to 1200*l.* while my expenditure continues the same, I accumulate annually 200*l.* more than I did before. If I save 200*l.* out of my expenditure, while my rofits continue the same, the same effect will be produced; 200*l.* per annum will be added to my capital. The merchant who imported wine after profits had been raised from 20 per cent. to 40 per cent., instead of purchasing his English goods for 1000*l.* must purchase them for 857*l.* 2*s.* 10*d.,* still selling the wine which he imports in return for those goods for 1200*l.;* or, if he continued to purchase his English goods for 1000*l.* must raise the price of his wine to 1400*l.;* he would thus obtain 40 instead

of 20 per cent. profit on his capital; but if, in consequence of the cheapness of all the commodities on which his revenue was expended, he and all other consumers could save the value of 200*l*. out of every 1000*l*. they before expended, they would more effectually add to the real wealth of the country; in one case, the savings would be made in consequence of an increase of revenue, in the other, in consequence of diminished expenditure.

If, by the introduction of machinery, the generality of the commodities on which revenue was expended fell 20 per cent. in value, I should be enabled to save as effectually as if my revenue had been raised 20 per cent.; but in one case the rate of profits is stationary, in the other it is raised 20 per cent.—If, by the introduction of cheap foreign goods, I can save 20 per cent. from my expenditure, the effect will be precisely the same as if machinery had lowered the expense of their production, but profits would not be raised.

It is not, therefore, in consequence of the extension of the market that the rate of profit is raised, although such extension may be equally efficacious in increasing the mass of commodities, and may thereby enable us to augment the funds destined for the maintenance of labour, and the materials on which labour may be employed.
(Works I:131-3)

This is probably realistic, but extremely difficult to formulate analytically. More recent economic theory has preferred to make reference only to the rate of profits and simply to assume that saving is zero if the rate of profits is lower or equal to a minimum rate, $r_{\min}$. This is the line we will follow here. In any case the passage by Ricardo can easily be interpreted even if this more usual concept of saving is followed. If the economy is not in a stationary state, that is, if $r_{\min} < 0.1$, the economy would be growing and this would increase employment year by year. In the example we have reconstructed, the increase in employment in the post-innovation economy is at the same rate as the pre-innovation economy and the positive effect described by Ricardo does not seem to be there. However, in the pre-innovation economy 8450 units of the marginal land are cultivated whereas in the post-innovation economy the cultivation involves only 4200 units of the marginal land. Therefore the post-innovation economy can grow without resorting to lands worse than land of quality 3 for any longer than in the pre-innovation economy, as maintained by Ricardo.

The more complex theory of saving envisaged by Ricardo contemplates that saving is also a consequence of reduced prices which, in turn, are a result of the innovation. In the examples we considered there is no reduction in price except for cloth when cloth is a luxury good. But in no example is there either saving or growth, since the rate of profits is low, at the stationary state level.

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8. Diffusion of the innovation

The analysis of the examples provided by Ricardo, although dynamic, abstracts from nonequilibrium considerations. In modern terms it corresponds to the analysis of the transverse. Ricardo is aware of this fact. "To elucidate the principle, I have been supposing, that improved machinery is *suddenly* discovered, and extensively used; but the truth is, that these discoveries are gradual, and rather operate in determining the employment of the capital which is saved and accumulated, than in diverting capital from its actual employment." (p. 395)

What happens if improved machinery is *not* suddenly discovered, and extensively used? Suppose for instance that in the first year only α machines are produced (even if the language may create confusion, we have to assume that machines are measured in a continuous magnitude, otherwise the pricing and the choice of technique would be totally different): in such a case the rent of land of quality 2 is not changed and therefore an extraprofit is obtained by use of the new machine. This means an increase of capital, which cannot be considered constant. Only the study of this dynamic process may provide some advance prefiguration of the employment rate once the long period has been obtained, but we can be confident that even if it will probably be higher than that seen earlier, it will certainly be below the level of employment prior to the innovation.

9. 'Machinery and labour are in constant competition'

We have reached the conclusion of chapter XXXI. There are two main points that Ricardo emphasizes in the conclusion. The first concerns the competition between machinary and labour:

> With every increase of capital and population, food will generally rise, on account of its being more difficult to produce. The consequence of a rise of food will be a rise of wages, and every rise of wages will have 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. (p. 395)

Ricardo also provides a historical illustration:

> In America and many other countries, where the food of man is easily provided, there is not nearly such great temptation to employ machinery as in England, where food is high, and costs much labour for its production. The same cause that raises labour, does not raise the value of machines, and, therefore, with every augmentation of capital, a greater proportion of it is employed on machinery. The demand for labour will continue to increase with an increase of capital, but not in proportion to its increase; the ratio will necessarily be a diminishing ratio. (p. 395)

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Two remarks are relevant here. Even in a sentence in which Ricardo presents a condensed expression of his result, he is very cautious: Machinery can *frequently* not be employed until labour rises. Ricardo's argument is based on examples and examples may prove that something could happen and cannot prove that something necessarily will happen. Not all commentators of Ricardo's text have been so cautious. Many neo-classical authors have argued that Ricardo was actually advocating the idea of technical substitution between labour and machinery. But examples showing opposite trends are possible: for instance, it is interesting to recall here a paper by Hagemann and Kurz (1976), in which two techniques are compared: one employs more roundabout capital than the other; nevertheless there is a switch point in which at a higher wage rate the less roundabout method is chosen.

Another remark concerns the distinction introduced by Schumpeter between invention and innovation. Ricardo comes close to grasping the distinction: even if the new machinery is technologically known, it is introduced only if the economic conditions are favourable to the introduction.

10. Policy

The last point mentioned by Ricardo concerns policy: "The statements which I have made will not, I hope, lead to the inference that machinery should not be encouraged" (p. 395). Ricardo provides two arguments. The first concerns the fact that improved machinery reduces the prices of commodities and therefore incomes estimated in commodities are higher: this increases savings and accumulation and then also increases the demand for labour. The other argument concerns the fact that economies are open and therefore if a country discourages the use of machinery whereas others do not, then competition drives production from the country which discourages the use of machinery to the others and demand for labour would be even lower in that country: "[b]y investing part of a capital in improved machinery, there will be a diminution in the progressive demand for labour; by exporting it to another country, the demand will be wholly annihilated" since "machinery cannot be worked without the assistance of men" (p. 397).

11. Concluding remarks

In this paper we have provided a textual analysis of Chapter XXXI of Ricardos *Principles*. More precisely we have reconstructed the examples that Ricardo elaborated in that chapter in terms of modern theory of production. The difficulty was to determine assumptions that Ricardo did not state explicitly. Ricardo made some assumptions to make his argument crystal clear. Among these are the stationary state and consequently the constancy of the rate of profits between the pre-innovation

economy and the post-innovation economy. This condition can be easily obtained in two cases: when the innovation concerns a non-basic commodity and when it concerns an agricultural commodity but the innovation changes neither the marginal land nor the technology used on the marginal land. Ricardo was conscious of these two facts and he seems to have used the second in his first example. Indeed such an example holds perfectly well if we assume that the new machine is specific to a quality of land that is marginal neither in the pre-innovation nor in the post-innovation economy. When the innovation is introduced in an industrial commodity (cloth) that is used by the workers, the rate of profits, and therefore the rate of growth, cannot be the same in the pre-innovation and in the post-innovation economy. A way to escape this problem consists in assuming that the innovation is introduced in a switch-point between the technique used before the innovation and that used after the innovation. Of course this is too strong an assumption and can be of some interest only if it gives information about events occurring near a switch point. We have also seen that Ricardo was cautious and never asserts that machinery necessarily reduces employment of labour. Indeed the reswitching debate has provided examples in which there are two switch-points among two techniques and whereas in one of them at a higher wage rate the more roundabout capital is chosen, in the other one the opposite happens.

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