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Tsoulfidis, Lefteris

University of Macedonia

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Lefteris Tsoulfidis

Professor, Department of Economics
University of Macedonia, 156 Egnatia Street
Thessaloniki, Greece
Tel.: 30 2310 891-788
E-mail: Lnt@uom.edu.gr

ABSTRACT
This article begins by utilizing Ricardo's numerical examples in the effort to derive theoretical statements about the changes in relative prices induced by changes in the distributive variables and production (turnover) times. According to Ricardo, the intertemporal growth rates in relative (market) prices are not too different from the respective growth rates of production (or equilibrium) prices and depend primarily on the growth rates of unit labor values and secondarily on capital intensities. The article continues by testing the extent to which Ricardo's main thesis by utilizing input-output data from the USA and China. The derived results lend overwhelming support to Ricardo's principles.

Keywords: David Ricardo; Value and distribution, Price-value deviations

JEL codes: B12; B14; B16; D24; D46, D57

1. INTRODUCTION

The objective of this article is twofold: first to present and critically evaluate Ricardo's theory of value as an explanation of the movement of relative prices of commodities consequent upon changes in their relative labor times; and second, to test the validity of this theory using data from actual economies. In spite of the fact that Ricardo defines clearly and repeatedly his theory of value, nevertheless, the differences in interpretation persist and have to do with the temptation of economists to read in Ricardo their own theory of value. Marshall (1920), for example, who was keen to stress the continuity of economic theory from classical to neoclassical economics, leaves no doubt about his purpose which is to frame Ricardo's theory of value into a (neoclassical) partial equilibrium approach by attributing to him a kind of a cost of production theory of price determination (Marshall, 1920, p. 672). By contrast, S. Hollander (1985) places Ricardo's theory of value in the tradition of general equilibrium analysis, which begins with Smith and culminates in Walras and the modern neoclassical economists; the idea behind this view is that prices and distributional variables (wages and profits) are co-determined. Stigler (1958, p. 366) argued that Ricardo held only an empirical labor theory of value according to which the relative labor times are the key determinants of the relative prices. This should not be interpreted to mean an analytical labor cost theory of value, because the labor time is one of the determinants of the relative prices along with others constituting the cost of production providing that rent is excluded in the estimation of the cost. In the heterodox camp, Sraffian economists (not all) emphasize the sections of Ricardo's *Works* that refer to his valiant but unsuccessful efforts to define an invariable measure of value which is presented as something akin to Sraffa's standard commodity while Ricardo's theory of value is regarded merely as a cost of production theory excluding rent (Steedman, 1982). Marxists economists, more often than not, treat Ricardo's theory of value as if it were similar to Marx's and then, not surprisingly, find incongruities. As we will argue, Ricardo was mainly concerned with the parity of relative labor times and natural prices and he used the word 'value' to indicate exchange ratios or relative prices. By contrast, Marx uses the same word 'value'

to indicate the socially necessary abstract labor time embodied in commodities and that his value is an approximate but firm center of gravity for natural prices (Tsoulfidis, 2010, ch.4 and the literature cited there).

The structure of the remainder of the paper is as follows: Section 2 discusses Ricardo's statements on the theory of value and his insistence for an explanation of the variations of relative prices induced by variations in relative labor times necessary for the production of commodities. Section 3 deals with Ricardo's labor theory of value and its modifications arising from the presence of fixed capital and rate of profit, the changes in wages as well as differences in turnover times. Section 4 shows that the effects of these variables on the movement of relative prices not only are minimal but also predictable. Section 5 tests empirically Ricardo's theory of value using data from input-output tables of the USA and China for meaningfully selected years. Section 6 summarizes and makes some concluding remarks.

2. RICARDO AND THE LABOR THEORY OF VALUE

Ricardo in his introduction of the *Principles* straightforwardly states that his major objective is to determine the laws of distribution in the economy, and he further argued that progress in such an endeavor is possible if and only if we have developed a consistent theory of value, that is, a theory of determination of relative prices (*Works*, I, pp. xiv-xv). Ricardo starts by endorsing Smith's labor theory of value, however, unlike Smith, he argued for the general applicability of this theory of value not only in the "early and rude state of society" but also to modern societies where production takes place with capital and waged labor. However, Smith's initially correctly stated principle that relative prices are determined by relative labor times, needs further qualifications in order to supersede a number of challenging issues that even in our times are regarded hard to deal with.

Ricardo already knew from Smith that market prices are determined by the ephemeral forces of demand and supply; but over time, he argued, these same ever-fluctuating market prices are attracted to something more fundamental than the simple

forces of demand and supply, that is, the natural prices which reflect the 'principle of equal profitability'. Thus, if in an industry there is excess profitability, that is, the rate of profit is above the economy-wide average, the acceleration of capital accumulation would increase the supply of this industry relative to its demand and the market price will fall to restore the economy-wide average rate of profit. The converse process will take place in the case of a shortage in profitability. Ricardo argued that the principal determinant of the movement in the resulting 'natural prices' are their respective labor times. Hence, there is a role for demand and supply; however, these two concepts have characteristically different meaning and content from those utilized, for example, by Malthus (cf. *Works* VIII, p. 279-80) and by extension by the usual neoclassical demand and supply schedules, each point of which represents a potential equilibrium price and quantity combination. In Ricardo, both demand and supply are regulated by profitability and by no means should be thought of as neoclassical schedules (Garegnani, 1984).

Ricardo accepts Smith's distinction between use value and exchange value and that the value in use of a commodity is merely a precondition for exchange (*Works*, I, p. 6). There are goods whose value derives from their value in use, however these goods are scarce and, therefore, are non-reproducible (e.g., rare paintings, coins, books and wine), whose value depends on the "varying wealth and inclinations of those who are desirous to possess them" (*Works*, I, p. 12) and not on the quantity of labor that went into their production. For the non-reproducible goods, Ricardo argued, that they are only an infinitesimally small percentage of the totality of the available goods, and that the overwhelming majority of goods are reproducible whose relative prices are determined by the relative quantities of labor and not on higher or lower wages:

> 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. (*Works*, I, p. 11).

The trouble with the above definition is that only the relative prices of commodities, that is, the visible part of the exchange, is known while the relative

quantities of labor times remain unknown, in Ricardo's time, because of the lack of data. Consequently, even in the case of two goods it would be nearly impossible to identify the exact source of this change. This is not a particularly difficult problem in our times because we can estimate the exact relative direct and indirect labor requirements per unit of output using the available input-output and employment data. It is interesting to note that despite of difficulties in the labor theory of value Ricardo continued his efforts for solutions and categorically excluded the easy way of giving in to a cost of production theory of value. For example, notes Ricardo:

> The main cause of change in relative values of commodities is the increase or decrease in the amount of labour required to produce them. (*Works,* I, p. 36)

Furthermore, Ricardo's cost price is in effect the natural price, which he treats as if it were the same with the actual market price. The possible deviations of the two kinds of prices, in the long-run, are expected to dissipate and so they are treated as if they were the same:

> It is the cost of production [= natural price] which must ultimately regulate the [market] price of commodities, and not, as has been so often said, the proportion between the supply and demand: the proportion between the supply and demand may, indeed, for a time, affect the market value of a commodity, until it is supplied in a greater or less abundance, according as the demand may have increased or diminished; but this effect will be only of temporary duration. (*Works*, I, p.232)

The want of data on labor time prompted Ricardo and the classical economists, in the search of an invariable measure of value; that is, a commodity whose production would always require the same amount of labor and whose value would remain the same regardless of changes in the distributive variables. In modern parlance, two are the requirements of an invariable measure of value: (a) zero relative price elasticity with respect to the technical conditions in production, that is, zero substitutability in production and (b) zero relative price elasticity with respect to changes in wages or profits. These two properties characterize a commodity as an invariable measure of

value, and as such it could be used as numéraire with aid of which we could identify the source of variation in the relative prices of all other commodities. Consequently, it could be possibly used for the estimation of the current value of output or wealth in a society and also make possible intertemporal comparisons. Ricardo devoted the rest of his intellectual life to the discovery of such a commodity which could be determined either practically or analytically (see *Works* I, pp. 42-44).[1] In effect, he investigated a number of possibilities, none of which gave absolutely satisfactory solutions because the production of all the commodities, he thought of, was subjected to technological change and therefore required different labor times over time. Ricardo at the end hypothesized gold the commodity that could, at least partially, perform the function of an "imperfect", but nevertheless the best available "measure of value" the "nearest approximation to truth" (*Works*, VIII, p. 279).

According to Ricardo, the value of gold was determined in the exact same way as with the other goods; that is, by the technique and, therefore, the necessary labor requirements in the production of gold which pretty much remain the same over reasonably long stretches of time (*Works*, I, p. 87). Furthermore, by using gold as a crude invariable measure of value, Ricardo managed to integrate his theory of value with his theory of money. In particular, although the labor time spent on the production of gold was supposed to be changing so slowly (compared to the other commodities) that it could be regarded approximately constant, making possible the determination of absolute prices along with money (gold) supply on the general price level. This distinction between the real (theory of value) and the monetary economy, as well as their interaction, are of critical importance to Ricardo's theory of value and its application to the theories of foreign trade, taxation and public debt (Tsoulfidis, 2010, 2013 and 2015).

[1] Ricardo in his last paper, written in 1823 admitted: "there is no such a thing in nature as a perfect measure of value" (*Works* IV, p.404).

Ricardo argued that the principle according to which the exchange ratios of reproducible goods are determined by relative labor times spent on their production was also correct in capitalism. However, the principle owed to be modified so as to account for the following three main features: the differences in capital-intensities between industries, the changes in wages or profits and differences in the completion of the production process or turnover time. The fundamental principle that the relative prices of reproducible commodities depend on the relative quantities of labor necessary for their production holds to a great percentage. Hence, it is important to stress that Ricardo refers to simple labor and that complex or skilled labor is reduced to simple through the operation of the market. More specifically, the differences in skills or in general qualities of labor are manifested in the market, as differential wages:

> The estimation in which different qualities of labor are held, comes soon to be adjusted in the market with sufficient precision for all practical purposes, and depends much on the comparative skill of the laborer, and intensity of the labor performed. *The scale, when once formed, is liable to little variation.* If a day's labor of a working jeweler be more valuable than a day's labor of a common laborer, it has long ago been adjusted, and placed in its proper position in the scale of value. (*Works*, I, pp. 20–21, emphasis added)

Ricardo further explained that the value (relative price) of commodities is determined not only by the current labor expended on its production but also by the past labor contained in plant and equipment. He notes:

> Not only the labour applied immediately to commodities affect their value, but the labour also which is bestowed on the implements, tools, and buildings, with which such labour is assisted [...] of the durable implement only a small portion of its value would be transferred to the commodity. (*Works*, I, p. 23)

In short, the relative prices of reproducible goods are determined by their respective labor times and that the fixed capital also affects the fundamental principle by transferring its exchange value onto the final product piecemeal through its depreciation. Clearly, Ricardo was fully aware of the depreciation of fixed capital but

for simplicity reasons, he hypothesized that depreciation is zero and that fixed capital lasts forever.

3. MODIFICATIONS OF THE THEORY OF VALUE

In a capitalist economy where production takes place with the employment of both labor and capital, Ricardo argued:

> The principle that the quantity of labour bestowed on the production of commodities regulates their relative value, considerably modified by the employment of machinery and other fixed capital. (*Works*, I, p. 30)

In other words, the presence of fixed capital and the rate of profit affect the relative prices but only in a limited and at the same time theoretically predictable way. In order to show the effects of the fixed capital, he hypothesized a simple numerical example of only two industries producing cotton and corn; each of the two industries employs 100 workers at an annual wage rate, w, of £50. He further supposed that the cotton industry, unlike the corn, uses a machine, K, worth of £5,500, which does not depreciate. The rate of profit, r, for convenience's sake is assumed at 10% and total profits, Π, that is, the product of the rate of profit times the sum of capital and wages, $r(K + wL)$. Thus, the cotton industry makes profits worth of £1,050 versus £500 of the corn industry.

One would say that with such large differences in profits earned as a result of the presence of fixed capital the cotton industry must sell at a price much higher than that of the corn industry. Ricardo shows, through an extreme for his hypothesis numerical example in which the relative prices are not out of touch from their respective relative labor times. Hence, the example is extreme in the sense that the corn industry uses no fixed capital at all as opposed to the capital-intensity of the cotton industry which is equal to £5,500/100=£55 per worker. The relative price of cotton to corn is $£6{,}050/£5{,}500 = 1.10$, that is, 10% higher than the respective relative direct labor times $100/100 = 1$. The deviation is attributed to the differences in the capital-labor

ratios, K/L, provided that the wage rate is the same in the production of both commodities.

Thus, the presence of capital and the rate of profit exert an increasingly limited effect on relative prices; if we think of Ricardo's falling rate of profit argument and also that the capital-intensity differences in reality are more moderate than those hypothesized. Thus, Ricardo's numerical example is judicious in that it illustrates his principle under extreme for his thesis assumptions. For example, instead of taking the two industries with realistic and, therefore, much smaller differences in capital-intensities, he shows that, even if differences in capital-intensities are far too large, deviations between relative prices and labor times remain relatively small.[2] Although Ricardo is not explicit, nevertheless, it can be shown that the relatively smaller price effect of capital intensities is amenable to abstract theorization and its precise size can be quantified. As a consequence, the effect of differences in capital-intensities on relative prices is secondary and theoretically predictable (at the level of analysis of two industries, at least) and that the labor expended remains the dominant factor in the determination of relative prices.

In Table 1 below, we modify Ricardo's numerical example by examining two commodities A and B and by inserting pragmatism without sacrificing generality, we hypothesize that the production of both commodities takes place with the employment capital and labor. Thus, we hav

[2] This feature of Ricardo's work, that is the derivation of key theoretical result on the basis of oversimplified numerical models and extreme hypotheses Schumpeter (1954, pp. 473-4) characterized it as "Ricardian Vice".

Table 1: Ricardo's modified numerical example

	K	wL	K/L	$\Pi = r(K + wL)$	$P = wL + \Pi$
Commodity A	£5,500	£5,000	£55	£1,050	£6,050
Commodity B	**£1,500**	£5,000	**£15**	£650	£5,650

The new givens as expected bring somewhat closer the relative commodity prices to the quantities of labor. More specifically, or

$$\frac{P_A}{P_B} = \frac{6{,}050}{5{,}650} = 1.07 > \frac{L_A}{L_B} = 1$$

where the subscripts A and B denote the two commodities. The deviation between the relative prices and the relative labor times spent on the production of the two commodities are derived from differences in the capital-intensities (K/L or K/wL). Here, it is important to note that in effect we are dealing with different capital-labor ratios since the wage rate is uniform in both commodities. It goes without saying that if the capital-labor ratios were the same then no deviation would have been observed between relative price P_A/P_B and relative labor time L_A/L_B. These results become much more pronounced, if we form the relative price of commodity A, namely

$$\frac{P_A}{P_B} = \frac{wL_A + r(wL_A + K_A)}{wL_B + r(wL_B + K_B)} \qquad (1)$$

and factoring out the relative labor time of the two commodities, we get

$$\frac{P_A}{P_B} = \left[\frac{L_A}{L_B}\right]\left[\frac{1 + r\left(1 + \frac{K_A}{wL_A}\right)}{1 + r\left(1 + \frac{K_B}{wL_B}\right)}\right] \tag{2}$$

By subtracting the relative labour times from both sides of the above equation, we get

$$\begin{aligned}\frac{P_A}{P_B} - \frac{L_A}{L_B} &= \left[\frac{L_A}{L_B}\right]\left[\frac{1 + r\left(1 + \frac{K_A}{wL_A}\right)}{1 + r\left(1 + \frac{K_B}{wL_B}\right)}\right] - \frac{L_A}{L_B} \\ &= \underbrace{\left[\frac{L_A}{L_B}\right]\left[\frac{r}{w + r\left(w + \frac{K_B}{L_B}\right)}\right]}_{\text{size of deviation}} \underbrace{\left(\frac{K_A}{L_A} - \frac{K_B}{L_B}\right)}_{\text{sign of deviation}}\end{aligned} \tag{3}$$

Relationship (3) shows that the relative prices depend on three factors, namely, the relative labor times, the capital intensities and the rate of profit (or wage). The numerical example is plausible (if not extreme in that it stands against Ricardo's thesis) because of the assumption of far too large differences in capital-intensities in the production of the two commodities. Notwithstanding the sizeable differences in capital-intensities; nevertheless, the size of the deviation between the relative prices and the relative quantities of labor is only 7%. Moreover, the sign of the deviation is predictable, since it depends on the difference of capital-labor ratio between the two industries provided that the wage rate is assumed uniform and constant in the face of hypothetical changes in the rate of profit.

Thus, we differentiate the relative price of the two goods with respect to (w.r.t.) the rate of profit and we get:

$$\frac{\mathrm{d}}{\mathrm{d}r}\left(\frac{P_A}{P_B}\right) = \frac{\mathrm{d}}{\mathrm{d}r}\left[\frac{wL_A + r(wL_A + K_A)}{wL_B + r(wL_B + K_B)}\right] = \frac{w(K_A L_B - K_B L_A)}{(wL_B + rwL_B + rK_B)^2} \tag{4}$$

Since, the denominator in relation (4) is always positive, it therefore follows that the sign of the above derivative depends exclusively on the sign of the numerator. In particular, the sign is determined by the term

$$K_A L_B - K_B L_A = \left(\frac{K_A}{L_A} - \frac{K_B}{L_B}\right) L_A L_B$$

Thus, we may write

$$\text{sign}\left[\frac{d}{dr}\left(\frac{P_A}{P_B}\right)\right] \quad \text{same as} \quad \left(\frac{K_A}{L_A} - \frac{K_B}{L_B}\right) L_A L_B \tag{5}$$

The profit rate also affects the relative prices, but only in a limited and theoretically predictable way while its effect lessens with the passage of time; hence, we invoke Ricardo's view of the falling in the long-run rate of profit. If, for example, we hypothesize a rate of profit of 5%, then the difference between relative prices and relative labor times is reduced to approximately 3.7% (see Table 2 and Figure 1) and in the extreme case of zero rate of profit relative prices become equal to their respective relative labor times and Ricardo's theory of value holds absolutely. Table 2 below presents selected results of our experiments with profit rates varying from zero and increasing by 2.5% until the hypothetical 100%. It is important to note that Ricardo was writing during a period of slowdown in economic activity in general and in Britain in particular and so the assumption of a 10% rate of profit is not only convenient in computations but also realistic enough for the actual state of the UK economy.[3]

[3] In effect, interest rates (on consols) during Ricardo's time were somewhat less than 5% (source: https://www.measuringworth.com/datasets/interestrates/result.php). Consequently, Ricardo's 10% assumption of the rate of profit is not only convenient in estimations but also realistic, if we invoke Smith's (1776, pp. 98-9) rule-of-thumb according to which the rate of profit is twice higher than the rate of interest on a safe loan.

Table 2: Relative prices and elasticities for selective rates of profit

r	0%	5%	10%	20%	40%	62.5%	70%	80%	90%	100%
P_A/P_B	1.000	1.037	1.070	1.127	1.210	1.275	1.293	1.31	1.332	1.347
e_r		0.026	0.053	0.086	0.114	0.119	0.118	0.117	0.115	0.112

In Figure 1 below, we show graphically the relationship between the rate of profit and the path of relative prices shown on the left-hand side (l.h.s.) axis

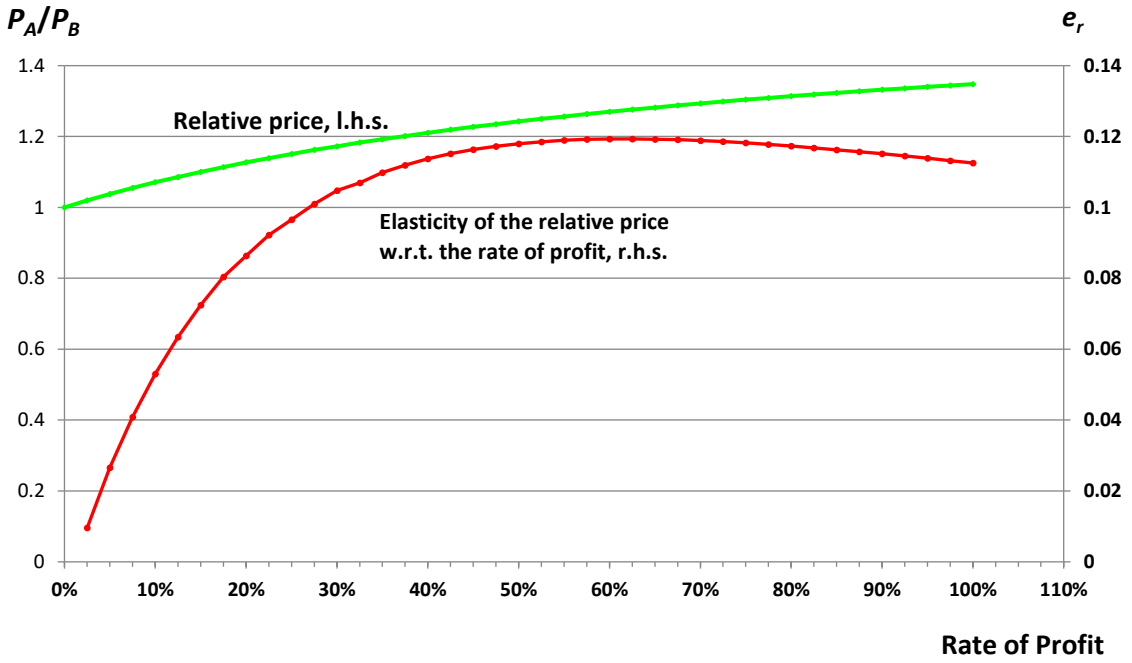


Figure 1: Relative price changes and elasticity price w.r.t. rate of profit

We observe that the deviations between relative labor values and relative prices are directly related to the rate of profit shown on the horizontal axis; starting from r=0% there is zero deviation between relative price and relative value, P_A/P_B / L_A/L_B=1. However, as the rate of profit increases the deviations also increase but at a decreasing rate. For example, when the rate of profit doubles (say from 10% increases to 20%), the deviation between relative prices and relative labor times increases from 7% to

12.7% (see Table 2 and Figure 1). From the results displayed in Table 3 and Figure 1, it becomes abundantly clear that past a point the relative price becomes increasingly less sensitive to changes in the rate of profit. In effect, the second derivative of relative price with respect to the rate of profit gives

$$\frac{\mathrm{d}^2\left(\frac{P_A}{P_B}\right)}{\mathrm{d}r^2} = -\frac{2w(wL_B + K_B)(K_AL_B - K_BL_A)}{(wL_B + rwL_B + rK_B)^3} < 0 \qquad (6)$$

Clearly, the capital-labor ratio in the production of commodity A is higher than that of commodity B, it follows that the second derivative will be negative, which is another way to say that the relative price path will be concave.

Thus, it comes as no surprise that the elasticity of relative price with respect to the rate of profit, e_r, displayed in Table 3 is smaller, in fact, much smaller than one in absolute value.[4] In particular, we have,

$$e_r = \frac{\mathrm{d}\left(\frac{P_A}{P_B}\right)}{dr}\frac{r}{\left(\frac{P_A}{P_B}\right)} = \frac{w(K_AL_B - K_BL_A)}{(wL_B + rwL_B + rK_B)^2}\frac{r}{\frac{wL_A + r(wL_A + K_A)}{wL_B + r(wL_B + K_B)}}$$

$$= \frac{w(K_AL_B - K_BL_A)}{(wL_B + rwL_B + rK_B)}\frac{r}{(wL_A + rwL_A + rK_A)} < 1 \qquad (7)$$

As a consequence, the elasticity of the relative prices with respect to the rate of profit measured on the right-hand side (r.h.s.) axis of Figure 1 increases each time by a decreasing rate until the attainment of a maximum and then for very high and, at the same time, unrealistic rates of profit turns to a downward direction. The results in Table 2, as well as those shown in Figure 1, are not far from those one expects to find in actual economies and, therefore, are realistic and lend overwhelming support to Ricardo's

[4] The estimation of elasticities, displayed in Table 2, is based on the application of midpoint formula.

intuition. If we now invoke Ricardo's 'fundamental law of distribution' that is, the inverse relationship between the wages and profits:

> [...] in proportion then as wages rose, would profits fall. (*Works*, I, pp. 77 and 111)

The idea is that an increase in the wage rate causes a decrease in the rate of profit and thus the estimated relative prices approximate even more closely the relative labor times. The converse will be true if the wage falls and the rate of profit increases. In both cases, Ricardo argues, the effect of a changing wage not only is minimal but also predictable.

In terms of Ricardo's based modified cotton-corn numerical example, a rising wage results in a fall in the rate of profit. The price of good A (cotton) in Ricardo's modified numerical example will change, since the producer estimates a profit on the machine equal to 9% instead of 10%. The final price, therefore, will fall to £5,945, and the price of good B (corn) which uses no fixed capital will become 5,585 and therefore the relative price P_A/P_B =1.064. Clearly, a fall in the rate of profit by 1% or what amounts to a substantial fall in profits by £170 (=10% x 17,000 – 9% x 17,000) total profits brings the relative price of production even closer to the relative labor times. Ricardo, after this kind of sensitivity analysis, arrives at the following conclusion:

> The greater effects which could be produced on the relative prices of these goods from a rise of wages, could not exceed 6 or 7 per cent.; for profits could not, probably, under any circumstances, admit of a greater general and permanent depression than to that amount. (*Works* I, p. 36)

In terms of our more general numerical example of Table 1, with capital employed by the two producers and by assuming that $r = f(w)$, $\frac{\partial r}{\partial w} < 0$ and $\frac{\partial K}{\partial w} = 0$, we get

$$\frac{\partial \left(\frac{P_A}{P_B}\right)}{\partial w} = \frac{\left[\frac{\partial r}{\partial w} w - (r+1)r\right](K_A L_B - K_B L_A)}{(wL_B + rwL_B + rK_B)^2} \qquad (8)$$

Result, which is very similar to the one derived above with a constant wage and a variable rate of profit. Because the bracketed term is always negative and the denominator is always positive and so the direction of price movements depends exclusively on the sign of capital-labor ratio differences. The negative second derivative and the elasticity of relative prices w.r.t. wages is much smaller than one are straightforwardly derived.

The third and final modification of Ricardo's theory of value relates to the differences between the starting time and that elapsing for the completion of the production cycle of a commodity. Ricardo notes:

> Suppose I employ twenty men at an expense of 1000*l.* for a year in the production of a commodity, and at the end of the year I employ twenty men again for another year, at a further expense of 1000*l.* in finishing or perfecting the same commodity, and that I bring it to market at the end of two years, if profits be 10 per cent., my commodity must sell for 2,310*l.;* for I have employed 1000*l.* capital for one year, and 2,100*l.* capital for one year more. Another man employs precisely the same quantity of labour, but he employs it all in the first year; he employs forty men at an expense of 2000*l.,* and at the end of the first year he sells it with 10 per cent. profit, or for 2,200*l.* Here then are two commodities having precisely the same quantity of labour bestowed on them, one of which sells for 2,310*l.*—the other for 2,200*l.*. (*Works*, I, p. 37)

Following Ricardo, we start with an initial amount of money of £2,000 (40 workers times a £50 annual wage) invested in commodities, A and B. In industry A, the total sum of £2,000 is invested in two equal installments in each of the two years required for the production of commodity A. At the end of the second year, the value of the commodity will be £2,310 estimated based on a rate of profit, r=10%, which is treated as a kind of opportunity cost by the producers. Thus, we may write

$$P_A = \underbrace{£1{,}000\text{x}(1+0.10)}_{\text{first year}} + \underbrace{£1{,}000\text{x}(1+0.10)^2}_{\text{second year}} = £2{,}310 \qquad (9)$$

The rationale in the above estimation is that the producer of commodity A takes into account a 10% profit rate on his invested capital in the first year during which he

held his money and did not put it in production and 10% on the investment in the second year. By contrast, in industry B all the money is invested in the first year so the exchange value of commodities will be:

$$P_B = \text{£}2{,}000\text{x}(1 + 0.10) = \text{£}2{,}200 \qquad (10)$$

From the above often-cited numerical example, we derive that the difference in the time of completion of the production process in the two industries utilizing the exact same amounts of labor and with uniform wage and profit rates end up to two (not very) different prices. The deviation between relative prices and respective labor times depends on the size of the exogenously assumed rate of profit and the differential turnover times. In particular, Ricardo notes:

> This case appears to differ from the last, but is, in fact, the same. In both cases the superior price of one commodity is owing to the greater length of time which must elapse before it can be brought to market. In the former case the machinery and cloth were more than double the value of the corn, although only double the quantity of labour was bestowed on them. In the second case, one commodity is more valuable than the other, although no more labour was employed on its production. The difference in value arises in both cases from the profits being accumulated as capital, and is only a just compensation for the time that the profits were withheld. (*Works*, I, pp. 37-38)

Thus, the time that elapses before a commodity reaches the market further modifies Ricardo's theory of value. However, the deviation of relative prices from relative labor times, despite the notable difference in turnover time is minimal and predictable. In particular, the relative price of the two commodities will be £2,300/£2,200=1.05, and the deviation from the respective labor times is only 5%. Alternatively, the proximity of relative prices to relative labour quantities is 95%! If we formalize Ricardo's example, and replace $n = 2$ and $r = 10\%$ we may write

$$\frac{P_A}{P_B} = \frac{wL(1+r) + wL(1+r)^n}{2wL(1+r)} = \frac{wL(1+r)[1 + (1+r)^{n-1}]}{2wL(1+r)}$$

$$= \frac{1 + (1+r)^{2-1}}{2} = 1.05 \qquad (11)$$

and the size and the direction of change in relative price w.r.t. turnover time, will be

$$\frac{\partial(P_A/P_B)}{\partial n} = 0.5 \ln(1+r)\,(1+r)^{n-1} \approx 0.05 > 0 \qquad (12)$$

while the change in the rate of change (the second derivative) will be negative

$$\frac{\partial^2(P_A/P_B)}{\partial n^2} = 0.5 \ln^2(1+r)\,(1+r)^{n-1} \approx -1.3 < 0 \qquad (13)$$

that is, the relative price of the good with the same investment but longer maturity time, other things equal, will be higher than its relative labour time; however as the turnover time increases the increase in relative price will be diminishing according to the second derivative of the above relation. Finally, the elasticity with respect to turnover time n and by assuming that $n = 2$ following Ricardo's numerical example, will be

$$e_n = \frac{\partial(P_A/P_B)}{\partial n}\frac{n}{(P_A/P_B)} = \frac{\ln(1+r)\,[(1+r)^{n-1}+1](1+r)^{n-1}}{4n} = 0.03 \qquad (14)$$

Of course, we may utilize more complex cases but for realistic examples, the deviations of relative prices from relative values in the face of moderate differences in turnover times are expected to be very small, as in this particular Ricardo's example in which we found that the elasticity of the relative prices with respect to turnover time is highly inelastic much less than one. If we now suppose that the turnover time, other things equal, increases from $n = 2$ to $n = 4$, then the estimated elasticity will be $e_n \approx 0.3$. This s another way to say that although we have a ten-fold increase in e_n, nevertheless, it remains in the vicinity of zero and much smaller than one; as a consequence, the price ratio of the two goods will differ from the value ratio by (only) 16.55%. These results lend support to Ricardo's thesis as this can be judged by the fact

that an excessively high percentage increase in the turnover (waiting) time and yet the change in relative price was by far too small. In the hypothetical and exceptional cases of goods with an extremely high production time, as for example the production of wine still the deviation of relative price is controllable. For example everything else constant and with $n = 10$ the relative price becomes ≈ 1.67 (or 67% deviation) and the elasticity $e_n \approx 0.2$, a result which indicates that the rate of increase in relative price is falling and the elasticity e_n for hypothetical and exceptionally high turnover times becomes less and less responsive.

From the above discussion, it follows that Ricardo's insights were reasonably formulated even on the basis of his simple numerical examples. However, it was impossible for him to make the next step, that is, to test the validity of his propositions empirically. Nowadays, economists have access to a wealth of relevant data, which combined with the currently available quantitative methods can subject to empirical testing Ricardo's theoretical insights. Thus, time and again it has been shown that the estimated natural prices of commodities are closely related to labor times contained in them. The old econometric studies (not too many) on the movement of relative prices (see Semmler, 1984, ch. 5) lend support to Ricardo's insights. More recently, the available input-output studies ascertain that the relative prices of production and the relative labor times are surprisingly close to each other and to actual market prices (Shaikh, 1984 and 2016; Tsoulfidis and Maniatis, 2002; Tsoulfidis and Mariolis, 2007; Tsoulfidis, 2008).

4. RICARDO'S PRINCIPLE OF RELATIVE PRICES TESTED

Ricardo's labor theory of relative prices is not necessarily cross sectional but intertemporal in the main (see also Shaikh 2016, ch. 9 and Kurz, 2018). In fact, Ricardo argued that changes in relative prices over time are explained not by changes in wages (and therefore a cost of production theory of value is ruled out) but rather by changes

in the labor time required for their production. Ricardo after emphasizing the limited effect of changes in wages on the relative prices, states emphatically:

> 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 [i.e., wages] it would be equally incorrect to attach much importance to it; and consequently, in the subsequent part of this work, though I shall occasionally refer to this cause of variation, I shall consider all the great variations which take place in the relative value [i.e., price] of commodities to be produced by the greater or less quantity of labour which may be required from time to time to produce them. (*Works* I, p. 34)

Hence, Ricardo argued that his theory of value has an intertemporal character and that the variations in relative (natural or market) prices depend principally on variations in relative labor times.[5] As a consequence, the focus of our empirical analysis will be on intertemporal comparisons of relative market prices against labor values and we will also test the extent to which relative market prices are affected by relative capital-intensities. Finally, we will also test to what extent if any natural prices (or Marxian prices of production) in the long-run are different from market prices. Thus, we may write the following econometric specification:

$$\ln(P_{t+n}./P_t)_j = \alpha + \beta \ln(V_{t+n}./V_t)_j + \gamma \ln(K_{t+n}./K_t) + u_j \qquad (15)$$

where P is the vector of price indexes of industries j at year t, n is the number of years ahead of the year t, V is the vector of unit (labor) values, α is the constant in the regression, β the elasticity coefficient of the unit labor values; γ is the elasticity of the capital intensity, K, u the stochastic term, ln is the natural logarithm and ./ stands for the element-by-element division between two vectors. Relation (15) indicates that the growth rates in the price indexes, which are no different from the respective growth rates in market prices, are determined primarily by the growth rates in relative labor times and secondarily by the growth rates in capital intensities. Hence, it is important to note that what is actually tested is the extent to which the growth rates in relative

[5] See *Works*, I, p. 232 cited on p.5 above.

vertically integrated labor productivities of industries determine the growth rates in the price indexes which are treated as proxies for the respective growth rates in market prices which in turn may be approximated by the prices of production. The idea is that market prices continuously fluctuate around their respective centers of gravitation, that is, their prices of production in Marx or natural prices in Ricardo and Smith and over the long run the ups and downs in market prices tend to cancel each other out and on average the market prices are not expected to be too different from the prices of production.

Hence it is important to note that we do not use as a dependent variable the growth rate of prices of production for the probable pitfall of testing an identity, an issue well known from the first studies (see Shaikh, 1984, 2016, ch. 3). This is the reason why that Shaikh (2016) is using the 45 degrees line and on the vertical axis places prices of production while on the horizontal the labor values and finds very high association. In the same book Shaikh (2016, p.399) refers to the pioneering study by Schwartz (1961) who tested the variability of prices indexes over the period 1918-1938 and found that despite wide variations in output (the depressionary years are included) and distributive variables the variations in prices was very limited and on average equal to 7.33%. A more extensive study by Puty (2007) referring to a much longer period from 1856 to1969 (see Shaikh 2016, p. 399) finds very similar results, relative prices change only by about 8% lending support to Ricardo's and also Marx's hypothesis. Although what we do here is implicitly found in the above studies, nevertheless the use of the growth rates of industries' price indexes as reliable proxies for the movement in respective market prices is not explicitly tested in these sources against their determinants.[6]

[6] Our approach is inspired, in part, by an exchange we had some years ago with Professor Takeshi Nakatani, who opined that we cannot get direct estimates of market prices through the use of input-output data and so objecting to the usual cross sectional studies which find high proximity of estimated values and prices of production to market prices. For this reason, he opted for the estimation of correlation coefficients of the ratio of unit labor values of industries over their prices in one period against the same ratio over another period, which is quite different from our proposed approach.

The input-output data that we use are for the economies of the USA and China are available from the World Input-Output Data (WIOD 2016) the link is http://www.wiod.org and were accessed on March 10, 2019, the database is at the 54 sectors level of detail although seven of China's industries had zero entries.[7] For this purpose, we estimate the matrix input-output coefficients initially in current prices, $\mathbf{A_c}$. The next step is to deflate (in terms of 2010 prices) this matrix in order to make possible, meaningful intertemporal comparisons. The deflation method is carried out in the following way

$$\mathbf{A} = \langle \mathbf{P} \rangle \mathbf{A_c} \langle \mathbf{P} \rangle^{-1}$$

where $< \mathbf{P} >$ is the diagonal matrix whose main diagonal contains the price index of each industry with 2010 as the base year and $\mathbf{A}$ is the matrix of technological coefficients obtained at constant prices.

The employment coefficients, $\mathbf{l}$, are derived as the ratio of the total wages of employed and self-employed population over the product of the real gross output of each industry times the economy's average deflated wage. Hence, the ratio of the real wage of an industry divided by the economy-wide average real wage gives us an approximate estimate of skills and at the same time reduces the complex labour to simple labour. Subsequently, the labour values of each industry are estimated as

$$\mathbf{V} = \mathbf{l}[\mathbf{I} - \mathbf{A}]^{-1} \tag{16}$$

The economy's real wage is equal to the average annual deflated money wage allocated over the basket of wage goods normally consumed by workers. Thus, we may write

[7] We also tested input-output data for Germany, USA, China, Greece and Japan of 34 industries with results very similar to the 54 industry structure that we opted for our presentation for the economy's of the USA and China. China's seven secondary industries (i.e., advertising, auxiliary financial activities, architectural activities, publishing, repair of motor vehicles and motorcycles, repair and installation of machinery) contain zero elements and are unquestionably of minimal importance and presumably aggregated to their closely related industries.

$$\mathbf{b} = \left(\frac{PCE_j}{\sum PCE_j}\right)\overline{w}$$

where $\mathbf{b}$ is the column vector of the basket of commodities (the real wage) normally purchased by workers with their money wage, and PCE stands for personal consumption of workers from industry $j = 1, 2, \ldots, 54$. Hence, the term in the above parenthesis stands for the share of each good in the total workers consumption expenditures.

The prices of production are estimated by the following equation:

$$\mathbf{P} = \mathbf{Pbl} + \mathbf{PA} + r\mathbf{PK} \tag{17}$$

where $\mathbf{P}$ is a row vector of relative prices of production, $\mathbf{b}$ is the column vector of the basket of goods that workers normally consume with their money wage, w=$\mathbf{Pb}$, and r is a scalar representing the economy's uniform rate of profit. Both prices of production (the left-hand side eigenvector) and the rate of profit (corresponding to the maximal eigenvalue) are estimated from the solution of the following eigenequation:

$$\mathbf{P}\mathrm{r}^{-1} = \mathbf{PK}[\mathbf{I} - \mathbf{A} - \mathbf{bl}]^{-\mathbf{1}} \tag{18}$$

The vector of capital stock for the 54 industries in constant 2010 prices is provided in the world input-output database http://www.wiod.org along with the necessary documentation for each country. The vector of capital stock is available at constant 2010 prices and the capital output ratio is derived by dividing element by element by the real output vector. The matrix of fixed capital stock coefficients was derived from the product of the column vector of investment shares of each industry times the row vector of capital stock per unit of output. The resulting new matrix of capital stock coefficients $\mathbf{K}$ possess the properties of the usual capital stock matrices derived and employed in the hitherto empirical studies. The idea is that the investment matrices contain many rows with zero elements (consumer goods and service industries do not

produce investment goods) and so the subdominant eigenvalues will be substantially lower (indistinguishable from zero) than the dominant which is another way to say that the equilibrium prices are determined almost exclusively by the dominant eigenvalue. The same is true with our case whose maximal eigenvalue will not be different from that we would obtain had we used a matrix of investment shares, while the difference between the dominant and the subdominant ones (which are nearly zero) is at maximum.

Finally, the row vector of vertically integrated value composition of capital (VIVCC), K, is the ratio of vertically integrated constant prices capital output matrix pre-multiplied by the vector of unit labor values the resulting new row vector is then divided (element-by-element) by the product of the unit labor values times the matrix of workers necessary consumption. Formally, we have

$$\mathrm{K}=\mathbf{VK}[\mathbf{I}-\mathbf{A}-\mathbf{bl}]^{-1}./\mathbf{Vbl}[\mathbf{I}-\mathbf{A}-\mathbf{bl}]^{-1}$$

For further details of estimations of various matrices and vectors, see Tsaliki, et al. (2018) and Tsoulfidis and Paitaridis (2017).

Having hypothesized that the growth in the interindustry relative price indexes are no different from the respective market prices, we proceed by subjecting to empirical testing this Ricardian hypothesis. In particular, whether or not the growth rates in relative market prices depend primarily on the respective growth rates in relative labor times and secondarily on the growth rates in capital intensities. We finally, subject to empirical testing the extent to which the intertemporal growth rates in prices of production are close to the growth rates of the price indexes or what amounts to the same, the growth rates of market prices. This is also a test of the extent to which Ricardo's (and also Marx's) hypothesis of the tendential equalization intertemporal prices of production to actual market prices holds.

The results from the economies of USA and China for the meaningfully selected years 2000, 2007 and 2014 and input-output data of the WIOD (2016) show

surprisingly high proximity. In both countries, we start with the year 2000 and compare it to the year 2007 and then we regress the year 2007 against that of 2014, in the effort to assess what extent if any the Great Recession affected Ricardo's 'law of value'. Finally, we tested the start year 2000 against the last year 2014 to see if Ricardo's principle holds in a much longer time span.

In Figure 2 below, we plot the growth rates in price indexes as well as the unit labor values of each of the 54 industries of the US economy, the first 3 graphs in the panel of 6 graphs. The regression lines and the kernel density functions indicate the similarities in distribution of both price changes and unit labor values. The notation is as follows: P_07_00 stands for the growth rate of the price index of each industry between the years 2007 and 2000. For the same period and reasons of visual clarity and convenience of presentation, we display the growth rate of unit labor values as V_07_00. The idea is that unlike market prices, which typically increase over time, unit labor values decline over time, as a result, of technological change and this is the reason that we got their growth rates starting from the terminal year 2007 to the start 2000. In case, that we did the other way around, the results would be the same albeit the slope coefficient would be with a negative sign. Ideally, both unit values and market prices are expected to be falling over the long run, although this is true for the unit labor values, it is not true for market prices in the post-WWII years at least, because of monetary issues and inflation, which are beyond the scope of the present paper. Similarly, with the other variables and pairs of years, where, PP_14_07 stands for the growth in prices of production over the period 2007-2014 while PP_14_00 indicates the growth rates of prices of production during 2014-2000 and so forth (see the last three graphs in Figure 2). Finally, K_07_00 (not shown in Figures 2 or 3) indicates the growth rate of the VIVCC between the years 2007 and 2000. Ditto for the other long periods and variables. We conduct the exact same test for the case of the Chinese economy and the results displayed in the panel of six graphs in Figure 3. The empirical findings strengthen the Ricardian and Marxian thesis that the intertemporal variations in market prices depend, to a large extent, on the

respective variations in labor values and that the growth in prices of production are not far from those in market prices.

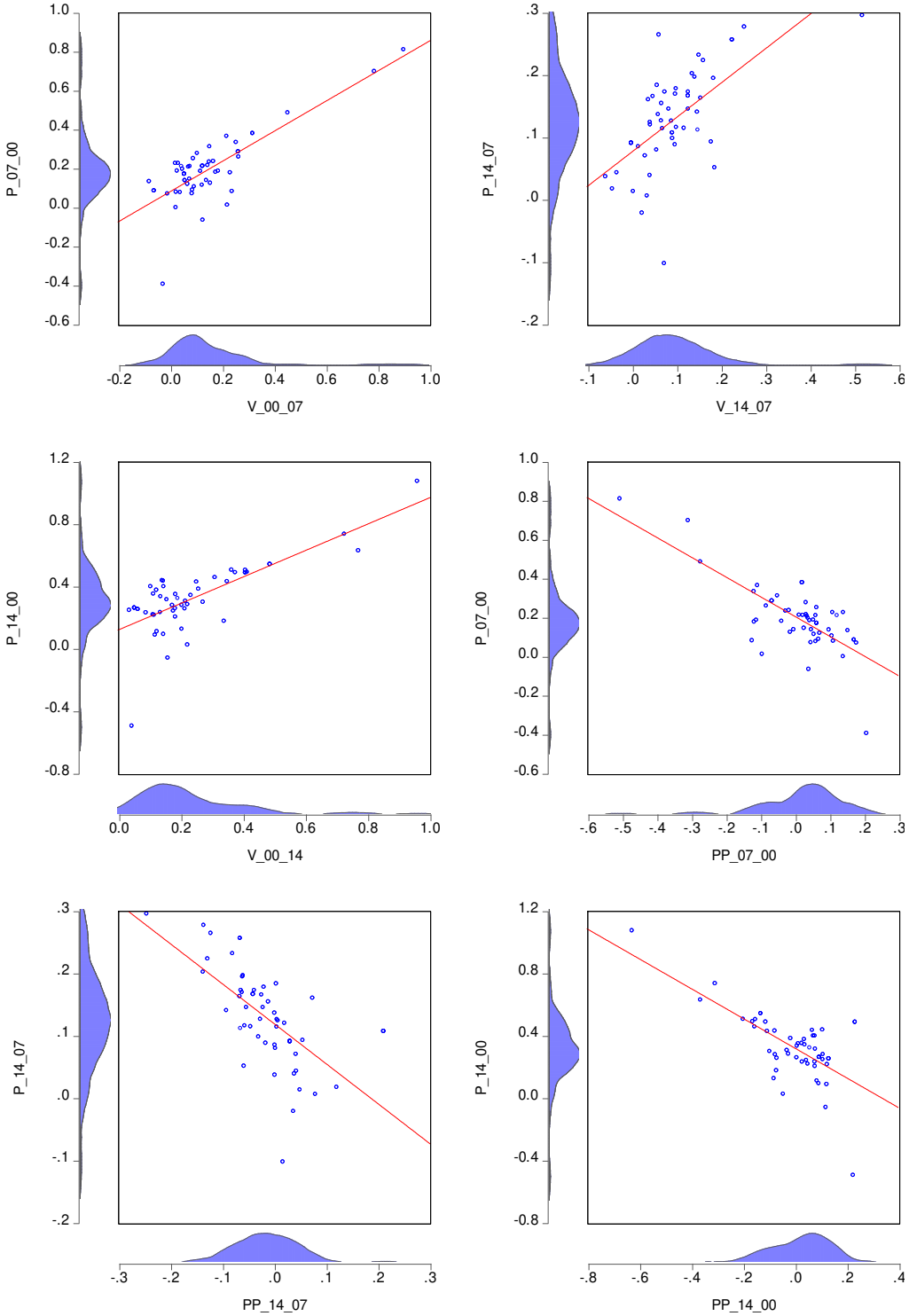
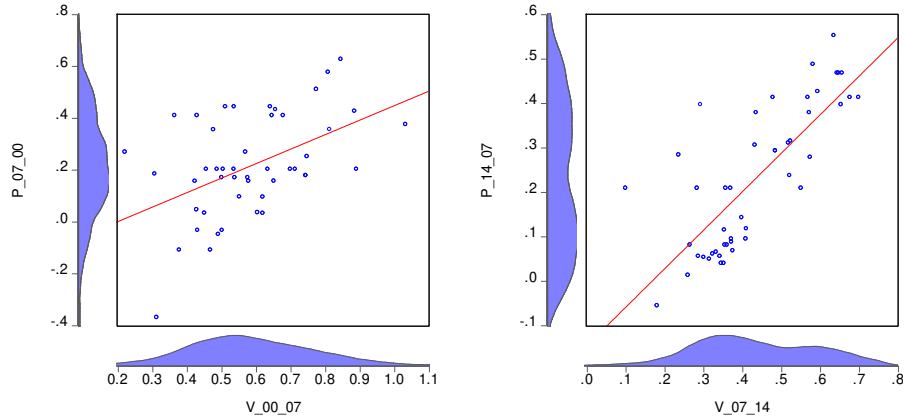
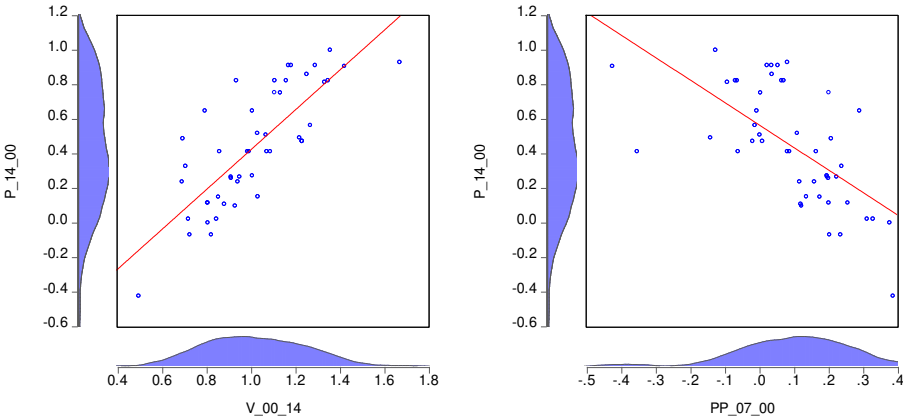


Figure 2: Labor values, Prices of Production vs. Market Prices, USA, 2000-2014





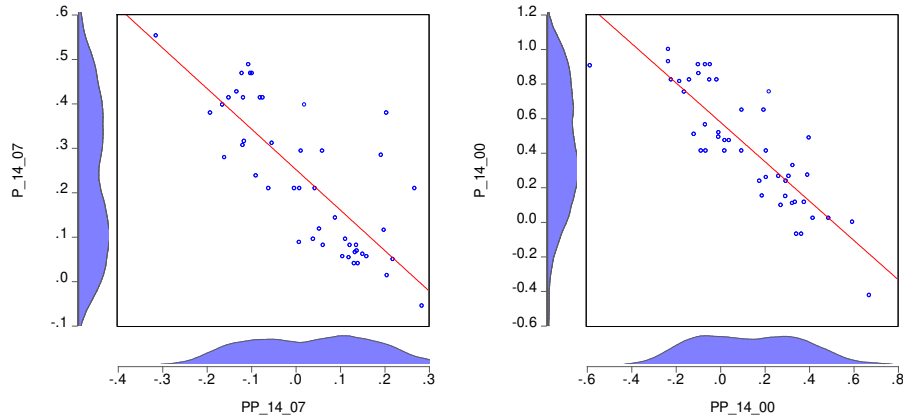


Figure 3: Labor values, Prices of Production and Market Prices, China, 2000-2014

The relative effects of unit labor values on market prices is obtained through the OLS regressions, whose results are displayed in Table 3 below for each of the two countries, time periods and set of variables. Clearly, the distribution of the deviations

in the three pairs of years under study are quite similar, indicating that the changes in unit labor values and prices keep close to each other over long stretches of time and they are nearly of the same magnitude and direction. Furthermore, the independent variables are statistically significant as this can be judged by the absolute values of the respective *t*-ratios in the parentheses and the adjusted R-squares are particularly high for cross-section regressions. Clearly, the variations in the unit labor values are always statistically significant in explaining the movement of market prices and the estimated elasticities are not far from unity lending support to the labor theory of value according to Ricardo.[8] It is important to note that the capital-intensity as captured in the variable K is also statistically significant but with an elasticity coefficient much lower than that of labor values. The capital-intensity is not statistically significant in the case of China and for the last two periods and the adjusted R-square suggests the elimination of this variable. Finally, the OLS regressions revealed the close proximity of prices of production to market prices, a result anticipated by both Ricardo and Marx.

Other important findings are that the Great Recession impacted on the US economy as this can be judged by the low elasticity of prices of production, in effect the elasticity coefficient of the PP_14_07, is the lowest and the overall performance is inferior to that of the other sub periods, in both countries. However when we examine the entire 2000-2014 period for the US economy, the elasticity coefficient of prices of production returns to nearly unitary; thereby, lending support to the view that in the long run the natural prices (or prices of production) tend to equality with market prices. The results for China are also extremely good especially in the last two periods (2007-2014 and 2000-2014) and certainly the Great Recession does not appear to have exerted any particular effect on the Chinese economy, at least with respect to Ricardo's labor theory of value.

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8 Ricardo, for instance, notes: "No law can be laid down respecting quantity, but a tolerably correct one can be laid down respecting proportions. Every day I am more satisfied that the former enquiry is vain and delusive, and the latter only the true objects of the science. (*Works*, VIII, pp. 278-79)

Table 3. Unit labor values, prices of production vs. market prices, USA and China[9]

Dependent Variable	Constant	Unit Labour Values	Vertically Integrated VCC	Prices of production	Adjusted R-squared
USA					
2000-2007	0.086 (4.74)	0.773 (9.44)			0.624
2000-2007	0.145 (7.31)	0.797 (11.5)	-0.493 (4.69)		0.732
2000-2007	0.208 (13.4)			-1.014 (8.16)	0.553
2007-2014	0.078 (6.69)	0.551 (6.05)			0.402
2007-2014	0.074 (6.99)	0.781 (7.48)	-0.311 (3.58)		0.512
2007-2014	0.120 (14.4)			-0.641 (5.99)	0.397
2000-2014	0.127 (4.02	0.847 (7.00)			0.543
2000-2014	0.205 (6.27)	0.857 (9.37)	-0.445 (4.33)		0.659
2000-2014	0.322 (14.9)			-0.955 (6.60)	0.445
CHINA					
2000-2007	-0.111 (1.20)	0.559 (3.67)			0.213
2000-2007	-0.259 (3.50)	0.851 (6.84)	-0.512 (5.99)		0.557
2000-2007	0.295 (12.4)			-0.839 (6.62)	0.482
2007-2014	-0.146 (3.00)	0.866 (8.13)			0.586
2007-2014	-0.130 (2.21)	0.891 (7.42)	-0.026 (0.458)		0.576
2007-2014	0.253 (16.7)			-0.912 (8.41)	0.601
2000-2014	-0.729 (5.19)	1.152 (8.58)			0.612
2000-2014	-0.611 (3.37)	1.160 (8.63)	-0.122 (1.02)		0.613
2000-2014	0.582 (19.8)			-1.139 (10.7)	0.712

[9] The figures in parenthesis are the absolute values of t-statistics.

5. CONCLUDING REMARKS

According to Ricardo, the required labor time spent on the production on commodities is the key determinant of natural prices, which in turn are theorized as the centers of gravitation of ever-fluctuating market prices. The unequal capital-intensities between industries, the changes in the income distribution as well as the differences in turnover times do affect the relative (natural) prices of commodities, but only in a limited and at the same time theoretically predictable way.

In this article, we further modeled Ricardo's theoretical insights and showed that one should not expect dramatic changes in relative prices in the presence of fixed capital and in the face of changes in the distributive variables or turnover times. These variables must be thought of secondary in importance for the paths of relative prices of commodities in comparison to principal determining factor which according to Ricardo is the relative labor times.

Thus, it came as no surprise that Ricardo's major theoretical prediction about the intertemporal variations in relative market prices, in the long run, is approximated by the natural price (or the price of production) and that the movement of market prices depends principally and decisively on the relative labor times is ascertained in the data from both the USA and China, that is, two major economies. Empirical results from a host of other countries, cross-sectionally and intertemporally corroborate Ricardo's foundational insights with respect to the determinants of relative prices.

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