Was Ricardo Right?

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Abstract

Records of rental agreements for agricultural land in England between 1690 and 1914 are used to develop an annual rental price index for agricultural land. This index displays a long run cointegrating relationship with indices for the price of agricultural output and agricultural wage rates. A vector error correction model illustrates the powerful long run causal influence of the price of agricultural output and wage rates on rents. By contrast, there is no evidence that rents cause wage rates or the price of agricultural output. Such results suggest that Ricardo was right when he posited that rent was a residual driven by increases in the price of agricultural output rather than the other way around. Matters are different however when the price of individual agricultural commodities is used rather than the price of agricultural output. In this situation there emerges a bidirectional causal relationship of the type envisaged by Jevons. Lastly our framework can also be used to measure the rate of technical progress in agriculture. While we cannot find a statistically significant level of technical progress before the industrial revolution, after 1785 the rate of technical progress is a brisk 1.8 percent per annum.

Keywords Ricardo, Land Rents, Causality

JEL code B31, Q15

1 Introduction

David Ricardo's *Principles of Political Economy and Taxation* published in 1817 continues to influence economic thinkers to this day. Along with the concept of comparative advantage as a basis for trade another famous section outlines Ricardo's theory of rent; basically an explanation of how surpluses accrue to landlords in an agricultural economy. Ricardo's insight was that the rent for a piece of land is a residual directly affected by the price of commodities produced using that land. It is impossible to landholders to force up commodity prices by increasing rents under the same commodity market conditions. And obviously, despite Ricardo's focus on farmland, the theory can be applied to any input which has supply restrictions.

The Ricardian views of rent were developed in the time of the Corn Laws and hence were more concerned with the theory of distribution. The Napoloeonic Wars had also prevented the country from importing Corn and the price of land had risen markedly as a consequence. Farms had been bought in the expectation of the continuation of high prices and landowners were pressing for protection from low cost imports.

In the 200 years that have elapsed since the publication of the third edition of *Principles of Political Economy and Taxation* numerous economists have formalised Ricardo's arguments most notably Samuelson (1959), Sraffa (1960) and Hollander (1979). One of the chief features of Ricardo's theory however, is the complete lack of empirical evidence to support the theory. Blaug (1956) states: "Think it fair to say that Ricardian economics is popularly depicted as having evolved in a state of almost complete factual ignorance."

Rather than looking at agricultural rents and the price of agricultural output empirical attempts looking for evidence of Ricardian surplus have tended to focus on the relationship between house prices and land prices. Most studies find that land prices and house prices are co-integrated and that house prices Granger cause land prices (Alyousha, 1998, Ooi, 2006, Oikarinen, 2009 and Rossini, 2012). By contrast Kim (2008) and Du (2011) find the relationship between house prices and land prices being bidirectional in nature.

Empirical tests of the Ricardian rent hypothesis in the context of agricultural land are much less common. The only significant study is that of Du (2008) which investigates the relationship between farmland rents and crop prices in Iowa. The paper's focus is on agricultural rents rather than land prices because these are "more likely reflect optimal pricing behaviour, as they are less vulnerable to asset bubbles and present less severe transaction cost issues". The key finding is that an increase of $1 in the price of corn leads to an $80-$114 increase in the rental price of land which is, according to the author, lower than the $135 that would result from full pass-through as predicted by Ricardo's theory. Possible reasons for this low pass-through are the existence of long term contracts, the impact of government subsidies and the bargaining power of local suppliers of labour and other inputs.

Empirical evidence from around the time of Ricardo is unsurprisingly, non-existent. The main purpose of this paper is, therefore, to test, for the first time, whether agricultural prices and wage rates Granger cause rents, or rents Granger cause agricultural prices and wage rates (or both). In order to conduct this test of the direction of causality we use two series on historical agricultural rents for England covering the period 1690-1914 (Turner et al, 1997) and a longer one for 1660-1912 focusing on charitable land (Clark, 2004). These datasets are augmented by information on agricultural commodity prices and farm wage data.

Our initial step is to investigate the time series-properties of the data. This is undertaken using Augmented Dickey-Fuller and Kwiatkowski–Phillips–Schmidt–Shin tests. The time

series data are then checked for the existence of a cointegrating vector using the Johansen cointegration test. Depending on the outcome of the test for cointegration a VECM model is constructed explaining the change in the value of each variable as a function of lagged values of all variable plus an error correction term. Using the VECM it is then possible to test for various forms of causality.

The results point to the existence of a long run relationship between rents, wages and prices. Furthermore the VECM methodology points unambiguously to a causal relationship running from prices and wages to rents. But this causal relationship holds only in the long run. There is by contrast no evidence to reject the hypothesis of no causal relationship running from rents to wages or prices. Such findings represent very strong evidence in support of Ricardo's theory. By comparison when one looks at the Granger causality tests for specific commodities one finds that there are many occasions in which an increase in rental values precipitates and increase in the price of specific commodities. This is wholly in keeping with the views of William Stanley Jevons (1835-1882) who argues that the possibility of employing land in another purpose means that rent is a causal factor in the pricing of commodities, and that rent and wages are identical in their relationship towards prices.

Although our chief focus is on determining the direction of the causal relation between prices, wages and rents, our framework can also be used to measure the rate of technical progress in agriculture in the periods before and during the industrial revolution. Our results suggest that there is no statistically significant level of technical progress over the period 1694-1784. Over the period 1785-1914 however the rate of technical progress is a brisk 1.8 percent per annum.

The reminder of the paper is structured as follows. Section 2 presents the views of classical economists on the topic. Ricardo's theoretical framework is presented in Section 3. The data employed in our analysis is described in Section 4 while Section 5 presents the results of the empirical findings. Extending our analysis to an analysis of the rate of technical progress, the findings are discussed in Section 6. Section 7 concludes.

2 Classical Economics and the Question of Rent

In *Principles of Political Economy and Taxation* published in 1817 David Ricardo (1772-1823) suggests that agricultural rents are determined by the price of wheat. According to Ricardo: "Corn is not high because a rent is paid, but a rent is paid because corn is high". Such views were in marked contrast to those of contemporary commentators who believed that landowners were increasing rents and that this then resulted in higher prices for agricultural produce.

Earlier classical economists had also concerned themselves with the question of rent.

Adam Smith (1723-1790) ventured the view that rent arose because of monopoly but also asserted that rent represents a surplus and that rent is completely determined by the price of agricultural output. He also realised that rent was linked to the fertility of the soil suggesting that land producing food always produces a rent.

Thomas Robert Malthus (1814 and 1815) also wrote about rent and in particular addressed himself to the question of whether landowners were the cause of high prices of corn to the obvious detriment of the labouring classes. He clearly regarded rent as a surplus and viewed rent as beginning on the most fertile land. He also recognised that rent is likely to be impacted by changes in the cost of production caused by changes in wages or technical

progress. Suggests lower wages will increase rent. Ricardo by contrast believes in a subsistence level of wages.

Ricardo points out that the interest of the landowner and the consumer diverge: it is always in the interests of the landowner to have high price and high production costs. Ricardo emphasises the importance of relative fertility (the fertility of land relative to that of land at the extensive margin). Rent will arise on superior land as soon as inferior land is brought under cultivation.

Despite its widespread acceptance the theory described by Ricardo continues to challenge by some and remains a subject of debate. This is partly because of the underlying assumptions and whether they describe perfectly the situation prevailing at the time when Ricardo wrote his book.

Ricardo suggested that the rental value of land was determined by the high price of wheat. A growing population generates increasing commodity prices requiring ever more marginal land to be brought into cultivation. According to Ricardo "Corn is not high because a rent is paid, but a rent is paid because corn is high". Such views were in contrast to a number of contemporary commentators who saw concurrent increases in the price of wheat and land and the rental price of land and who concluded that landowners were increasing rents and that these increases were passed on to the general population in the form of higher wheat prices.

In support of his ideas Ricardo (1817) put together a model intended to illuminate the nature of agricultural rents. Landowners, tenant farmers and labourers are the three components of the wheat-growing economy. Tenant farmers rent agricultural land from landowners and employ labourers who in turn help them to produce wheat which is the sold in the market place. Ricardo described rent as a periodic payment for the "original and indestructible powers of the soil". Its value is determined by the cost differential between typical agricultural land and an alternative piece of land whose production costs were such that its cultivation resulted in no surplus. The greater the price of agricultural output the larger the surplus and the greater the difference between the typical plot of agricultural land and land at the extensive margin.

In Ricardo's framework the economy evolves to a steady state in which the only party to benefit from the existence of agricultural surpluses are landowners. Ricardo relied on the writings of Malthus (1798) to argue that wages fall to a level consistent with mere subsistence (the "iron law" of wages). Ricardo's views on the effects of improvements in agricultural technology only entered the 3rd edition of *Principles of Political Economy and Taxation* where he argued that technological improvements would benefit only landlords through an increase in agricultural surplus resulting in ever greater rent.

Unlike John Stuart Mill (1806-1873) who followed closely the analysis of Ricardo, Jevons argues: "That able but wrong-headed man, David Ricardo, shunted the car of Economic science on to a wrong line, a line, however, on which it was further urged towards confusion, by his equally able and wrong-headed admirer John Stuart Mill". Jevons in *Theory of Political Economy* published in 1871 argues that the possibility of employing land in another purpose means that rent is a causal factor in the pricing of commodities, and that rent and wages are identical in their relationship towards prices. The rent that can be received from other potential uses of the land is a causal factor in the pricing of agricultural commodities.

James Buchanan (1929) resolves this disagreement by pointing to the fact that the study of rent belongs properly in an analysis of both exchange and distribution. The Ricardian views of rent were developed in the time of the Corn Laws and hence were more concerned with the theory of distribution. Nowhere in Ricardo's *Principles of Political Economy and Taxation*

does it mention any specific kind of agricultural produce. Neither does Ricardo mention land shifting between forms of agricultural activities.

One of the chief features of Ricardo's theory however is the distinct lack of empirical evidence to support the theory. Blaug (1956) goes as far as to say "Think it fair to say that Ricardian economics is popularly depicted as having evolved in a state of almost complete factual ignorance."

3 The Ricardian Theory of Rent

In this section we present the way that modern economic analysis formulate the Ricardian theory of rent. The following equations form the basis of our empirical analysis.

Let *P* represent the price of output, *W* represent the wage rate, *X* represent output obtainable from cultivating a unit area of land, *R* represent the rent per unit area of land and *L* the amount of labour. The variable *t* is a time trend intended to capture technical progress and π is gross revenue. The maximisation problem of the farmer can then be represented as follows:

$$\pi = (PX - WL) + \lambda(X - X(L, t))$$

Solving for the optimal level of *L* and the implied level of output results in the gross profit function given by:

$$\pi = (P, W, t)$$

The surplus from agricultural production is entirely absorbed by the rent such that:

$$(P, W, t) - R = 0$$

There thus ought to be a long term (trend stationary) relationship between the variables *P*, *W* and *R*.

4 Data

In our analysis we use two datasets reporting records of rental values for England (Clark, 2002 and Turner et al., 1997). These datasets differ with respect to the years they cover and the type of agricultural land ownership they represent.

Clark (2002) uses the records of lands held by charities to estimate farmland rental values over the period 1500-1914. These are taken from the reports of various historical inquiries into the activities of charitable organisations. The database accompanying his paper contains 32,149 records of land rental leases from 1394-1912 and records both the acreage together with either a recorded rental price land value or an assumed rate of return. Many plots of land are observed more than once. In addition to these variables the dataset also contain information on plot location, type of lease, type of land, the presence of buildings, the existence of tithes and many other things besides. The rental index used in this paper is the

area-weighted average of all direct rental records and does not include rents derived from information on land values and an assumed rate of return. The rental index is moreover incomplete up until the year 1660 and dominated by observations from later time periods. Rather than interpolate missing observations we decided to analyse the data from the years 1660-1912.

Turner et al (1997) provide historical agricultural rents for 1690-1914. They collect assessed and received rents from large estates from different sources (estate records, The Royal Commission on Agriculture and other printed sources). The number of observations per estate varies significantly. Once more our index is formed by the area-weighted average of rent received. In addition to these variables the dataset also contain information on plot location and many other things besides.

Comparing the two datasets, the Turner et al dataset contains observations on 77.1 million acres while the Clark data set contains observations on 1.1 million acres (2 per cent of the agricultural land). The Clark index is noticeably higher than the Turner et al one although the two series move in close harmony with one another. Clark notes that the charity sample is not entirely representative as charities tend to have smaller than average plot sizes and be located in more densely-populated areas. Clark (1998) and Turner et al (1998) debate the relative merits of these two sources of data on rents.

In general, the share of farm tenure is high in England over that period despite the fact that tenants necessarily have to make investments in the land such as its fertilisation, crops and fixtures etc.[1] Why was not owner-occupation the tenure arrangement of preference? Share-cropping is when the tenant is too poor to face the uncertainties associated with agricultural production. Evidence is cited by Offer (1991) that the system of short term tenancies was increasing and the practice of long term tenancies, or even tenancies in terms of named lives were falling from around the time of the 16th century. Nevertheless in bad years landowners might have allowed tenants' rents to accumulate. Offer suggests that the prevailing system of tenure was a device for ensuing that landownership was a stable activity. He reports to the semblance of a competitive market system for the allocation of tenancies but that turnover of tenants was low suggesting suggests that the system arose because of the prior appropriation of land by the elite in the acts of enclosure that commenced around the 16th century.

The existence of long terms contracts for renting land might mean that the price of agricultural commodities affects rental prices only in the long run.

Turning to prices, Clark (2004) contains an annual price series for 26 agricultural commodities in England from 1209-1914. His price index is geometric with weights corresponding to the output shares of each commodity. These shares are not constant but nevertheless remain fixed for extended periods. Prices for the same commodity obtained from different sources are corrected for differences in units of measurement, quality and location. Sub-indices are provided for arable, meat, dairy, wool, pasture and wood products as well as an overall farm price index.

In our analysis we use the farm price index as well as prices of individual commodities, most notably wheat. This is because of uncertainties regarding the weights attached to different commodities in any overall price index and the fact that, historically, wheat has been the single most important crop, but partly because of the fact that to be pedantic Ricardo developed his theory specifically positing a relationship between rental values and the price of corn.

[1] On the eve of the First World War 90 per cent of agricultural land was cultivated by tenant. For a discussion of the history of the institutional arrangements governing farm tenure from 1750-1950 see Offer (1991).

There is a fair correspondence between the agricultural price index and the price index for wheat. These price indices data reflect the effect of poor weather such as the year without summer (1815), the Napoleonic wars (1803-1815), the effects of the Corn Laws (1815-1846) in maintaining prices above the point that they might otherwise have been as well as the reduction of prices towards the end of the time period caused by the reduction in the price of ocean going transportation and the influx of imports from Eastern Europe and the New World.

Farm wage data is taken from Clark (2007) who provides a documented history of agricultural wages in England from 1209-1869. After 1869 wages are taken from Fox (1903) who records weekly wages from 125 farms in England and Wales. From 1902-1914 the agricultural wages are taken from Bowley (1937). These data are then joined together to form a single wage index.

Agricultural rents, the prices of all agricultural outputs and wages are all measured in nominal terms. The rental price indices, the agricultural prices and wheat price indices, and the wage price index and displayed in Figures 1-4 respectively. The data is summarised in Table 1.

Table 1. The Data (1660-1914)

Variable	No. Obs.	Mean	Std. Dev.	Min.	Max.
RENT_T (£/acre)*	225	0.69	0.40	0.11	1.41
RENT_C (£/acre)*	253	0.91	0.51	0.11	3.43
WAGE (p./day)	255	16.90	7.25	8.77	33.78
PRICE (index)	255	75.47	23.82	42.9	152.40
WHEAT (s./bu.)	255	5.45	2.20	2.57	14.84
BARLEY (s./bu.)	255	3.18	1.23	1.33	8.69
OATS (s./bu.)	255	2.16	0.76	1.11	5.39
PEAS (s./bu.)*	243	3.73	1.38	1.79	10.90
BEANS (s./bu.)	255	3.61	1.42	1.63	9.74
POTATOES (s./cwt.)*	156	4.60	1.93	1.79	10.54

Source: See text.

**Data for PEAS covers the period 1660-1902 while data for POTATOES is available for 1761-1914 only. RENT_C (Clark) covers the years 1660-1912 while RENT_T (Turner et al.) 1690-1914.*

Figure 1. Agricultural rents in England (1690-1914)

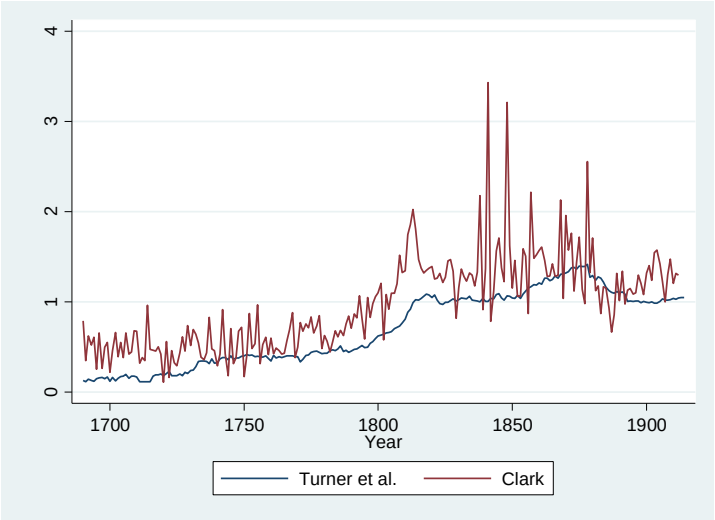


Figure 2. Agricultural prices in England (1690-1914)

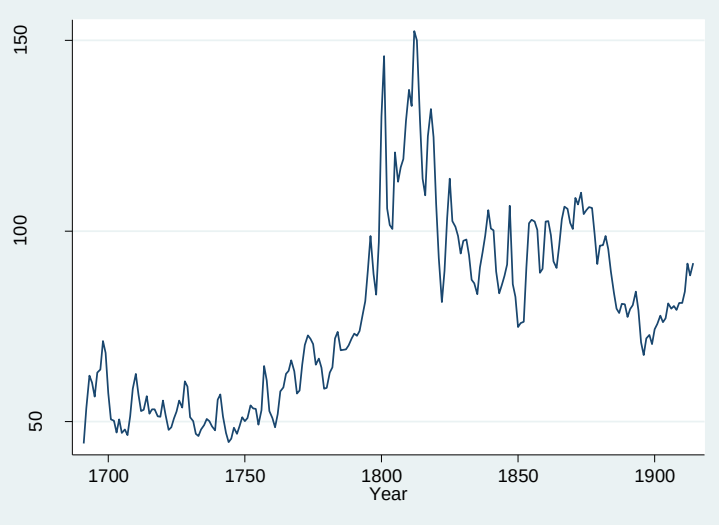


Figure 3. Farm wages in England (1690-1914)

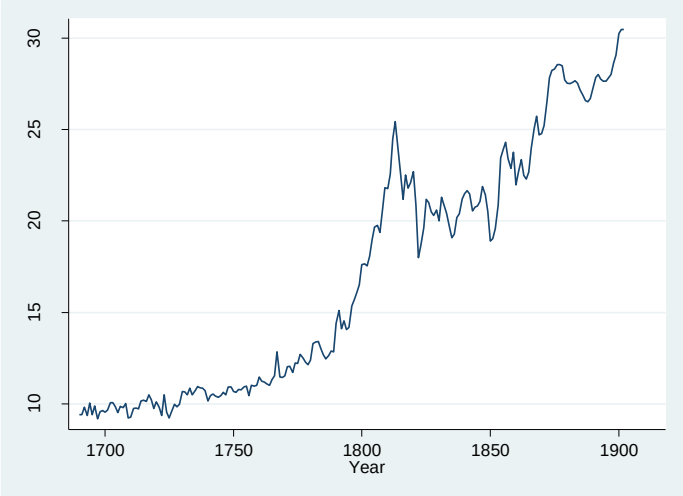
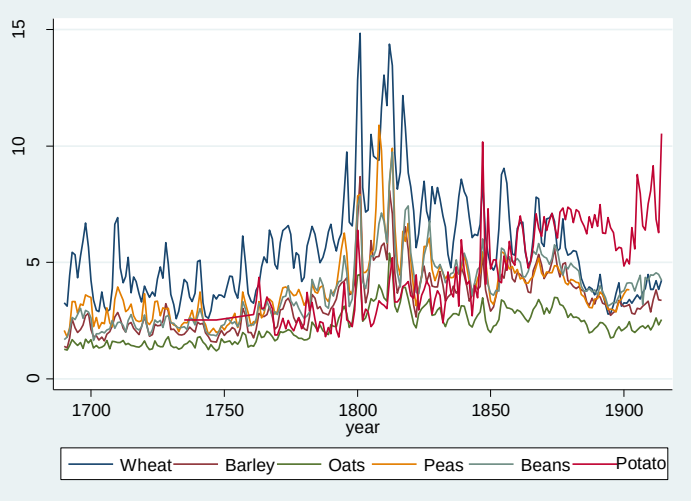


Figure 4. Prices of individual commodities (1690-1914)



5 Empirical Evidence

The main purpose of this paper is to test whether agricultural prices and wage rates Granger cause agricultural land rents or if rents Granger cause agricultural prices and wage rates (or both). The Ricardian story is consistent with the finding that agricultural prices and wages cause rents; it is not consistent with rents causing agricultural prices and wages. Matter are however different when we consider specific agricultural commodities. Here it is likely that there is a two-way causal relationship between agricultural rents and the prices of these commodities. In order to test the direction of Granger causality we adopt methods similar to those used in the literature albeit in other contexts.

Our initial step is to investigate the time series-properties of the data. This is undertaken using Augmented Dickey-Fuller (ADF) tests and also Kwiatkowski–Phillips–Schmidt–Shin (KPSS) tests (Kwiatkowski et al., 1992). Variables are tested to determine whether they are stationary around a mean or are trend stationary. The ADF and KPSS tests differ with respect to the null hypothesis: the null in the ADF test is that the data contain a unit root whereas in the KPSS the null is that the data are stationary. Both tests permit the optional existence of a time trend.

Tables 2 and 3 present results of the two test statistics, ADF and KPSS, for specifications with constant and time trend and those with a constant only. Variables enter either in levels or first differences. Results in Table 2 cover the period 1690-1914 corresponding to the Turner et al. data while results in Table 3 refer to the period 1660-1912 corresponding to the Clark data. The results of the KPSS are unambiguously pointing to stationarity of the data when first differences are used irrespective if a time trend is included or not. Results of the ADF test are more mixed especially for the period 1660-1912. If first differences are used together with a constant and a time trend the data is stationary with the exception of OATS.

Table 2. Tests of the Unit Root Hypothesis: 1690-1914

	ADF test statistic		KPSS test statistic	
Variable	with constant and trend	with constant	with constant and trend	with constant
Levels				
RENT_T	-0.852	0.942	0.203**	1.81***
WAGE	-1.919	1.539	0.239***	1.89***
PRICE	-1.690	-0.595	0.278***	1.19***
WHEAT	-2.047	-1.635	0.36***	0.464**
BARLEY	-2.497	-0.555	0.286***	1.14***
OATS	-2.395	-1.109	0.317***	1.17***
PEAS[a]	-2.324	-1.377	0.264***	0.815***
BEANS	-2.241	-0.815	0.312***	1.29***
POTATOES[a]	-4.967***	0.166	0.123*	1.53***
First Difference				
ΔRENT_T	-6.006***	-5.004***	0.11	0.154
ΔWAGE	-8.536***	-1.108	0.0521	0.299
ΔPRICE	-12.729***	-11.334***	0.0528	0.0834
ΔWHEAT	-12.675***	-12.578***	0.0442	0.113
ΔBARLEY	-13.846***	-13.285***	0.0393	0.0828
ΔOATS	-12.264***	-2.756***	0.0469	0.0877
ΔPEAS[a]	-14.032***	-13.617***	0.0451	0.0828
ΔBEANS	-12.127***	-12.174***	0.0437	0.0849

ΔPOTATOES[a]	-2.227	-2.274**	0.0384	0.103

*Note that * means significant at 10 per cent, ** means significant at 5 per cent and *** means significant at 1 per cent.*

**Data for PEAS cover the period 1690-1902 while data for POTATOES is available for 1761-1914 only.*

Table 3. Tests of the Unit Root Hypothesis: 1660-1912

	ADF test statistic		KPSS test statistic	
Variable	with constant and trend	with constant	with constant and trend	with constant
Levels				
RENT_C	-3.175**	-1.332	0.2**	1.79***
WAGE	-1.515	1.365	0.375***	2.04***
PRICE	-1.879	-1.142	0.219***	1.32***
WHEAT	-2.421	-2.406**	0.3***	0.542**
BARLEY	-2.838*	-1.201	0.24***	1.31***
OATS	-2.585	-1.481	0.251***	1.37***
PEAS[a]	-2.741*	-2.275**	0.229***	1.03***
BEANS	-2.593	-1.292	0.265***	1.49***
POTATOES[a]	-5.121***	-0.171	0.132*	1.5***
First Difference				
ΔRENT_C	-20.924***	-0.936	0.0142	0.0142
ΔWAGE	-10.800***	-9.894***	0.0391	0.242
ΔPRICE	-11.044***	-2.123**	0.0706	0.0701
ΔWHEAT	-12.574***	-3.685**	0.0677	0.073
ΔBARLEY	-12.946***	-1.282	0.051	0.0503
ΔOATS	-1.674	-0.333	0.069	0.0691
ΔPEAS[a]	-14.488***	-14.203***	0.0541	0.0563
ΔBEANS	-12.676***	-12.252***	0.0506	0.0527
ΔPOTATOES[a]	-10.006***	-10.310***	0.0263	0.0278

*Note that * means significant at 10 per cent, ** means significant at 5 per cent and *** means significant at 1 per cent.*
[a]Data for PEAS cover the period 1690-1902 while data for POTATOES cover the period for 1761-1912.

Next, we investigate if a cointegrating vector exists for our time-series data using the Johansen cointegration test (with time trend). The trace statistic presented in Table 4 indicates for r=2 all variables (RENT, WAGE and PRICE) in the two models are stationary.

Table 4. Johansen's Test for Cointegration

Dataset	H_0	H_A	Trace statistic	5 per cent critical value
Turner et al. (1690-1914)	r=0	R=>1	48.2810	42.44
	r=1	R=>2	13.5855*	25.32
	r=2	R=>3	3.2691	12.25
Clark (1660-1912)	r=0	R=>1	137.0456	42.44
	r=1	R=>2	24.3009*	25.32
	r=2	R=>3	4.5836	12.25

In the following, we use the outcome of the test for cointegration to construct a VECM model explaining the change in the value of each variable as a function of lagged values of all variable plus an error correction term. Using the VECM it is then possible to test for various forms of causality. These include short run, long run and overall causality.

For example, in order to test whether prices Granger cause rents it is necessary merely to test whether the coefficients on the lagged value of ΔP are statistically significant in the equation for ΔR and whether the variable *ECT* being the error correction term is statistically significant for long run causality. For overall causality a test on the statistical significance of both ΔP and *ECT* is performed.

$$\Delta R_t = \alpha + \beta ECT_{t-1} + \sum_t \gamma \, \Delta R_{t-1} + \sum_t \delta \Delta P_{t-1} + \sum_t \theta \Delta W_{t-1} + \varepsilon$$

Note that the cointegrating regression includes a time trend and the VECM includes a constant term. Identifying the appropriate number of lags is an important aspect of the model development process. We use the SBIC criterion to help determine the number of lags. We evaluate Granger causality for four different models because we have two different series for agricultural rents and the two different series for agricultural prices. Tables 4a and 4b present the results. Results of specifications replacing PRICE by WHEAT are presented in the Appendix (Tables A1-A3). Tables 5a and 5b report the results of the test statistics.

Table 4a. Vector error correction model 1690-1914

	ΔRENT_T$_t$	ΔPRICE$_t$	ΔWAGE$_t$
ECT$_{t-1}$	-0.0205489	2.331905	0.0520119
	(-3.48)	(1.66)	(0.36)
ΔRENT_T$_{t-1}$	-0.2017747	13.86479	0.4723812
	(-2.98)	(0.86)	(0.29)
ΔRENT_T $_{t-2}$	0.0574833	33.68943	1.365067
	(0.84)	(2.06)	(0.82)
ΔRENT_T $_{t-3}$	0.0599723	3.479232	-0.9859716
	(0.90)	(0.22)	(-0.61)
ΔPRICE$_{t-1}$	0.0001609	0.1063408	0.023666
	(0.53)	(1.46)	(3.21)
ΔPRICE$_{t-2}$	-0.0001244	-0.1997483	0.0093481
	(-0.42)	(-2.84)	(1.31)
ΔPRICE$_{t-3}$	-0.0002359	-0.3098356	0.002045
	(-0.77)	(-4.27)	(0.28)
ΔWAGE$_{t-1}$	0.0091459	1.467431	0.0514365
	(2.94)	(1.98)	(0.68)
ΔWAGE$_{t-2}$	0.0021442	-0.6391999	-0.1414527
	(0.68)	(-0.85)	(-1.87)
ΔWAGE$_{t-3}$	0.0046643	-0.302238	-0.0950127
	(1.50)	(-0.41)	(-1.26)
CONSTANT	0.0024579	-0.0026585	0.1201631
	(1.31)	(-0.01)	(2.65)
R-sq	0.1993	0.2341	0.1392

Z-statistics in parenthesis.

Table 4b. Vector error correction model 1660-1912 (Clark rent index)

	$\Delta RENT\_C_t$	$\Delta PRICE_t$	$\Delta WAGE_t$
ECT_{t-1}	-0.5195037	-.6078464	-0.5223041
	(-4.73)	(0.26)	(-2.0)
$\Delta RENT\_C_{t-1}$	-0.5199338	-0.6787084	0.2791129
	(-4.97)	(-0.30)	(1.12)
$\Delta RENT\_C_{t-2}$	-0.472077	0.2773168	0.104012
	(-5.33)	(0.15)	(0.49)
$\Delta RENT\_C_{t-3}$	-0.1710974	0.8831339	-0.0713745
	(-2.65)	(0.64)	(-0.47)
$\Delta PRICE_{t-1}$	0.0015179	0.0875144	0.0255207
	(0.47)	(1.29)	(3.35)
$\Delta PRICE_{t-2}$	-0.0001855	-0.2148213	0.0116838
	(-0.06)	(-3.26)	(1.58)
$\Delta PRICE_{t-3}$	-0.0005962	-0.3094654	0.0015305
	(-0.19)	(-4.54)	(0.20)
$\Delta WAGE_{t-1}$	0.0331955	1.141521	-0.1920873
	(1.15)	(1.86)	(-2.81)
$\Delta WAGE_{t-2}$	0.0311049	-0.3434394	-0.1221928
	(1.08)	(-0.56)	(-1.79)
$\Delta WAGE_{t-3}$	0.0442022	-0.3450663	-0.0887292
	(1.61)	(-0.59)	(-1.35)
CONSTANT	-0.0732111	0.0270929	0.0412884
	(-3.08)	(0.05)	(0.73)
R-sq	0.5501	0.2042	0.1348

Z-statistics in parenthesis.

Table 5a. Chi-sq tests of causality (1690-1914)

	RENT_T			PRICE			WAGE		
	SR	LR	Overall	SR	LR	Overall	SR	LR	Overall
RENT_T				4.51	2.75*	5.77	1.27	0.13	1.37
PRICE	1.44	12.11***	14.78***				12.97***	0.13	13.94***
WAGE	10.63**	12.11***	23.54***	5.04	2.75*	7.69			

*Note that * means significant at 10 per cent, ** means significant at 5 per cent and *** means significant at 1 per cent.*

Table 5b. Chi-sq tests of causality (1660-1912)

	RENT_C			PRICE			WAGE		
	SR	LR	Overall	SR	LR	Overall	SR	LR	Overall
RENT_C				1.13	0.07	2.43	3.12	3.99**	5.83
PRICE	0.35	22.38***	27.04***				14.92***	3.99**	26.94***
WAGE	3.97	22.38***	31.76***	4.85	0.07	5.02			

*Note that * means significant at 10 per cent, ** means significant at 5 per cent and *** means significant at 1 per cent.*

The results of the VECM methodology point unambiguously to a causal relationship running from prices and wages to rents. But this causal relationship holds only in the long run.

Our explanation for this is the existence of long term rental contracts alluded to earlier. There is by contrast no evidence to reject the hypothesis of no causal relationship running from rents to wages or prices. These findings hold irrespective of whether we employ the Clarke or the Turner rent data. When replacing the price index PRICE with the price for WHEAT the results are unchanged (Tables A1-A3 in the Appendix). Such findings represent very strong evidence in support of Ricardo's theory.

There are also some unanticipated findings concerning the existence of a short run relationship running from prices to wages (for the Clark data also long run). Although unanticipated it is easy to rationalise this finding in terms of either costs pushing wages or alternatively it may have an efficiency wage or subsistence interpretation.

By comparison when one looks at the Granger causality tests for specific commodities one finds that there are many occasions in which an increase in rental values precipitates and increase in the price of specific commodities (Table 6). This is in keeping with the views of Jevons. The only real exception to this is the price of wheat which is not impacted by the rental value of land. The explanation for this is that wheat is the single most important commodity and as such it is very similar to the price index for all agricultural commodities.

For the Clark data we find fewer cases in which rental values affect specific commodities. This can be explained by the fact that Clark contains far less acre-years of observations. As pointed to above, Clark covers 2 per cent of the agricultural land and is limited to land held by charities.

Table 6. Chi-sq tests for overall causality for individual commodities

		RENT	WHEAT	BARLEY	OATS	PEAS	BEANS	POTATOES
Turner et al (1690-1914)	RENT_T		7.64	16.49***	16.71***	4.56	14.65***	21.88***
	WHEAT	20.12***						
	BARLEY	12.50**						
	OATS	14.36***						
	PEAS	23.13***						
	BEANS	15.89***						
	POTATOES	1.99						
Clark (1660-1912)	RENT_C		2.37	3.46	2.63	0.61	4.35	25.30***
	WHEAT	26.63***						
	BARLEY	28.63**						
	OATS	32.85***						
	PEAS	28.90***						
	BEANS	31.70***						
	POTATOES	20.090***						

*Note that * means significant at 10 per cent, ** means significant at 5 per cent and *** means significant at 1 per cent.*

6 Discussion

Although our focus has been on determining the direction of the causal relation between prices, wages and rents, our analysis can also be used to measure the rate of technical progress in agriculture in the period prior even to the industrial revolution. Although ours is by no means the first attempt to empirically estimate this parameter we believe that it is the first attempt to do so using an approach based on the link between agricultural profitability and rental values. Other approaches to estimate the rate of technical progress appear to employ a production function approach which may be vulnerable to unusual production conditions at particular locations. By contrast our estimates are much more broadly based and are estimated over a much longer period of time. Such estimates however derived are interesting not merely in their own right but because they enable one to comment on the competing hypotheses of an agricultural revolution taking place contemporaneously with the industrial revolution (Crafts, 1985) or an early agricultural revolution (Allen, 1999).

In order to obtain estimates of the rate of technical progress in agriculture it is necessary to adopt a specific functional form. It is convenient to use a Cobb Douglas approximation to the profit function for this purpose.

$$LnR_t = \alpha + \beta T_t + \gamma LnP_t + \delta LnW_t + \varepsilon$$

The coefficient on the linear time trend *T* represents the rate of technical progress.

The profit function is meant to be linear homogenous in the price of inputs and outputs. This restriction can be imposed by insisting that:

$$LnR_t - LnW_t = \alpha + \beta T_t + \gamma(LnP_t - LnW_t) + \varepsilon$$

In what follows we estimate the rate of technical progress with and without the assumption of linear homogeneity. We also consider how technical progress in agriculture changed over the course of the period leading up to the industrial revolution and beyond. Of the many agricultural inventions perhaps the invention of the threshing machine in 1784 was most significant since according to Clark (2007) threshing was an activity which absorbed one quarter of the labour employed in agriculture. We therefore consider separately the periods pre and post 1784.

Table 7. Estimates of the rate of technical progress in agriculture

	Turner et al	Clark	Linear Homog. (Turner et al)	Pre-1784 (Turner et al)	Post-1784 (Turner et al)
	Ln(R)	Ln(R)	Ln(R)-Ln(W)	Ln(R)	Ln(R)
Ln(P)	2.191106	0.9639357		-3.577733	2.846316
	(5.20)	(5.51)		(-5.05)	(6.25)
Ln(W)	-3.963011	0.3224256		6.721471	-2.011422
	(-4.35)	(1.14)		(2.69)	(-2.57)
Ln(P)-Ln(W)			1.698122		
			(2.91)		
YEAR	0.0286024	0.0016014	0.0074864	0.0011895	0.0179264
	(5.80)	(1.20)	(3.34)	(0.16)	(3.53)
CONSTANT					

Note: P is the farm price index.

The long run parameters are taken from the ECM.

Considering first the estimates obtained from the Turner et al data for the period 1694-1914 we see that the rate of technical progress is 2.8 percent per annum and that this is statistically significant at even the one percent level of confidence. However, using the Clark data, which runs from 1664-1914, we see that the rate of technical progress is imprecisely estimated and not even statistically different from zero at the 10 percent level of confidence.

Reverting once more to the Turner et al data we impose linear homogeneity and obtain an estimate of 0.7 percent per annum once again significant at the once percent level of confidence. The imposition of linear homogeneity however results in a very significant loss of fit meaning that we cannot place much faith in this estimate. Lastly we divide the data into different time periods. There is no statistically significant level of technical progress over the period 1694-1784. Over the period 1785-1914 however the rate of technical progress is a brisk 1.8 percent per annum. It does therefore appear that there is little evidence in favour of an early agricultural revolution as envisaged by Allen (1999).

7 Conclusions

One of Ricardo's most important contributions to economics is establishing the link between wages, prices and rents. But despite its importance to both historians and analysts making pronouncements based on the Ricardian hypothesis there have been no attempts to empirically validate the underlying assumption that changes in aggregate prices simply feed through into changed prices for rents. This paper has employed recently obtained historical data to test the key proposition put forward by Ricardo. The results strongly support Ricardo's great insight whilst at the same time upholding the contrary view put forward by amongst others that other great 19th century economist Jevons. Basically the overall price of agricultural commodities causes land rents but, in the case of individual agricultural commodities, this causality runs in both directions. This provides empirical confirmation of one of the most important insights of agricultural economics and something contained in every agricultural economics textbook: the idea of rent as a 'residual'.

Such findings provide further insight into the effects of the Corn Laws i.e. the belief that the effect of maintaining protection from low-cost imports would have benefitted landowners. There is even confirmation of another effect identified by amongst others Ricardo, namely the impact of higher agricultural prices on the agricultural wage. It is clear that the increase in agricultural wages following an increase in agricultural prices is at least consistent with

Ricardo's subsistence view of wages and the idea of higher prices cutting the labour force until the nominal wage rate has risen enough to restore the real value of wages.

The same data also provides an estimate of the rate of technical progress measured over a very lengthy period of time. The estimates point to a period of rapid technical progress over the period as a whole but progress that is most discernible only after the period of one of the most important agricultural innovations. These results do not give any support to the view that the agricultural revolution was in any sense out of synch with the wider industrial revolution.

Although the data that have been used to undertake these analyses are remarkable they are not unique. Similar data exist for other European countries and it would of course be interesting to repeat the analyses contained in this paper using data from elsewhere.

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APPENDIX

Table A1. Johansen's Test for Cointegration (RENT, WHEAT, WAGE)

Dataset	H_0	H_A	Trace statistic	5 per cent critical value
Turner et al. (1690-1914)	r=0	R=>1	56.8457	42.44
	r=1	R=>2	12.9101*	25.32
	r=2	R=>3	2.4145	12.25
Clark (1660-1912)	r=0	R=>1	128.7530	42.44
	r=1	R=>2	30.2269	25.32
	r=2	R=>3	6.2070*	12.25

Table A2a. Vector error correction model 1690-1914

	$\Delta RENT\_T_t$	$\Delta WHEAT_t$	$\Delta WAGE_t$
ECT_{t-1}	-0.018307	0.4266417	0.105607
	(-3.74)	(2.25)	(0.87)
$\Delta RENT\_T_{t-1}$	-0.2030777	2.808199	1.057816
	(-3.01)	(1.08)	(0.63)
$\Delta RENT\_T_{t-2}$	0.0565306	4.180572	1.513209
	(0.83)	(1.59)	(0.89)
$\Delta RENT\_T_{t-3}$	0.049415	-1.125126	-0.6502017
	(0.75)	(-0.44)	(-0.40)
$\Delta WHEAT_{t-1}$	0.0009914	0.0901089	0.1107826
	(0.51)	(1.20)	(2.29)
$\Delta WHEAT_{t-2}$	-0.0024119	-0.2973878	0.0175194
	(-1.36)	(-4.33)	(0.40)
$\Delta WHEAT_{t-3}$	-0.0028238	-0.2228293	0.078596
	(-1.51)	(-3.09)	(1.70)
$\Delta WAGE_{t-1}$	0.008658	0.131776	0.1035898
	(2.88)	(1.13)	(1.39)
$\Delta WAGE_{t-2}$	0.0028352	-0.0908065	-0.110227
	(0.93)	(-0.77)	(-1.46)
$\Delta WAGE_{t-3}$	0.0051885	-0.0739357	-0.1407095
	(1.7)	(-0.63)	(-1.86)
CONSTANT	0.0030489	-0.0285137	0.1157209
	(1.62)	(-0.39)	(2.48)
R-sq	0.2179	0.2504	0.1101

Z-statistics in parenthesis.

Table A2b. Vector error correction model 1660-1912 (Clark rent index)

	$\Delta RENT\_C_t$	$\Delta WHEAT_t$	$\Delta WAGE_t$
ECT_{t-1}	-0.5002442	0.3271884	-0.3790771
	(-4.69)	(0.91)	(-1.45)
$\Delta RENT\_C_{t-1}$	-0.5350375	-0.4005458	0.1763055
	(-5.25)	(-1.16)	(0.71)
$\Delta RENT\_C_{t-2}$	-0.4842464	-0.107907	0.0092022
	(-5.57)	(-0.37)	(0.04)
$\Delta RENT\_C_{t-3}$	-0.1853698	-0.1005899	-0.1432341
	(-2.91)	(-0.47)	(-0.92)
$\Delta WHEAT_{t-1}$	0.0058768	0.0647799	0.1033111
	(0.28)	(0.92)	(2.03)
$\Delta WHEAT_{t-2}$	-0.0182291	-0.3124156	0.0412303
	(-0.98)	(-4.94)	(0.90)
$\Delta WHEAT_{t-3}$	-0.000648	-0.2256399	0.0561008
	(-0.03)	(-3.35)	(1.15)
$\Delta WAGE_{t-1}$	0.0266018	0.1348695	-0.1485592
	(0.93)	(1.40)	(-2.13)
$\Delta WAGE_{t-2}$	0.0283312	-0.0772198	-0.0997891
	(1.01)	(-0.81)	(-1.45)
$\Delta WAGE_{t-3}$	0.0384218	-0.0700121	-0.1082171
	(1.40)	(-0.76)	(-1.62)
CONSTANT	-0.0444488	0.025404	0.0805829
	(-2.14)	(0.36)	(1.59)
R-sq	0.5494	0.2263	0.0848

Z-statistics in parenthesis.

Table A3a. Chi-sq tests of causality (1690-1914)

	RENT_T			WHEAT			WAGE		
	SR	LR	Overall	SR	LR	Overall	SR	LR	Overall
RENT_T				3.60	5.08**	7.64	1.29	0.75	1.82
WHEAT	5.98	13.97***	20.12***				6.21	0.75	6.21
WAGE	12.00***	13.97***	28.94***	2.37	5.08**	7.50			

*Note that * means significant at 10 per cent, ** means significant at 5 per cent and *** means significant at 1 per cent.*

Table A3b. Chi-sq tests of causality (1660-1912)

	RENT_C			WHEAT			WAGE		
	SR	LR	Overall	SR	LR	Overall	SR	LR	Overall
RENT_C				2.36	0.82	2.37	3.07	2.11	4.50
WHEAT	1.07	21.99***	26.63***				5.08	2.11	12.51**
WAGE	3.08	21.99***	34.16***	3.70	0.82	4.54			

*Note that * means significant at 10 per cent, ** means significant at 5 per cent and *** means significant at 1 per cent.*