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Digitizing and analyzing historical maps to provide new perspectives on the development of the agricultural landscape of England and Wales

Keywords: Tithe maps; agricultural history; GIS; multilevel modelling; georeferencing.

Summary
The primary aim of this paper is to demonstrate that the careful digitizing of historical maps provides tremendous potential for the historian and historical geographer. A Geographical Information System (GIS) has been used to combine the geographic and economic information contained in the Tithe Survey of the mid Nineteenth Century with other socio-economic and environmental data for parishes in Britain's agricultural heartland and in southwest Wales. The Tithe Survey records of a parish typically consist of a map and an accompanying schedule or apportionment. The schedule lists the landowner, occupant, cultivation type and rent charge payable to the tithe owner. The map shows the location of each individual field listed in the schedule. All the maps and schedule data required for the project have been input into a GIS and consist of approximately 40,000 individual agricultural fields spread throughout 40 individual parishes of England and Wales. Sophisticated analysis enables us to assess such issues as the relative significance of landowner, occupant and natural resource endowments on agricultural productivity as well as identifying and quantifying how these factors interact in different spatial contexts. Whilst the results are clearly significant, the paper will underline the need to be mindful of the pitfalls of using such precise methods and techniques with historical sources and that end-user requirements should be of paramount concern when embarking on such an enterprise. The design of a suitable data model and the selection of an appropriate methodology for data input are of critical importance.

Research Context

The view that British agriculture was revolutionized between 1750 and 1850 is based mainly on the dramatic improvements in farm productivity achieved in certain parts of England, most notably in lowland wheat-growing regions such as East Anglia. Studies of agricultural change in England and Wales credit wealthy landowners with leading the movement for reform. These "improvers" experimented with new crops, promoted crop rotation and the use of manure and lime to enrich the soil, and sought to increase efficiency and productivity by investing in better machinery, improving drainage and consolidating their landholdings. Scholars have also pointed to the growth of urban markets as a powerful spur to increase productivity and to expand agriculture beyond its traditional locations. Lastly, the replacement of customary rights of tenure with tenancy agreements on fixed terms of years gave tenant farmers new incentives to increase production while husbanding the soil and taking better care of the properties they rented. We know little, however, about the extent to which these changes penetrated all areas of Britain and especially those that were still poorly connected to the market economy in the early 19th century.

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Aims and objectives

The primary aim of the research is to assess the relative significance of landowner, occupant and natural resource endowments on agricultural productivity as well as identifying and quantifying how these factors interact in different spatial contexts. The objective is to apply multilevel modelling to enable the project to adopt both extensive and intensive research approaches. Patterns of broad variation of agricultural productivity, as indicated by the tithe rent charge can be identified across and between different spatial contexts and, combined with intensive case studies, to understand process operation at the local scale. This paper represents preliminary results of a novel application of spatial and statistical modelling techniques to an historical problem and demonstrates the fundamental benefits of converting historical maps to digital form.

The Tithe Surveys of England and Wales

The early part of the nineteenth century was a period of considerable social and economic change in Britain. Expansion of agriculture during the Napoleonic Wars (1793-1815) was followed by depression. The fluctuating fortunes of farmers were characteristic of the period and nowhere more so than in southwest Wales. The depression in rural areas resulted in the migration of people to the towns where growth was accelerating due mainly to industrial expansion. Consequent overcrowding, increased regularity in outbreaks of disease and a growing threat of popular revolt were all of major concern to the government. As a result, the mid-nineteenth century witnessed a series of measures which aimed to centralise the control of the state and thus maintain order. As part of this process select committees collected information, commissions secured local agreements and surveyors mapped the land. Indeed, surveyors and valuers during the nineteenth century were enjoying a boom period, surveying plans for canals, railways, roads and housing estates (Kain and Prince, 1985).

Tithe payments

The Tithe Commutation Act of 1836 was just one measure among many that attempted to establish order during a period of extreme change. The Established Church was increasingly regarded as archaic, out of touch with contemporary issues and maintained through outdated, inconsistent and inequitably enforced customs and legislation. Criticism of the Church focused on the payment of tithes. In some places the payment of tithes went back to the ninth century. Originally, tithes consisted of payments in kind, such as crops, wool, and milk. They represented one tenth of a landowner's agricultural profit that was used in support of the parish church. In theory there were three types of tithe payment: predial, mixed and personal tithes. Predial tithes were payable on all fruits of the earth and subject to an annual increase. These include corn, hay, wood, fruit, and other crops. Mixed or agistment tithes were payable on all things nourished by the ground such as cattle, lambs, colts, calves, wool, milk, eggs and honey. Personal tithes were levied on the profits of human labour such as milling and fishing. Tithes on grain, hay and fruit were generally higher than others. The tithe on grain could be one fifth of the annual rent on arable land (Kain and Prince, 1985). Rent-charges could be lowered by converting land to other uses. For example, moving arable land over to fallow, waste, or pasture, or fodder crops such as turnips could reduce the tithe

payment. A tithe would be payable on the agistment category. Clover and meadow would be classed as predial tithes if cut for hay, but agistment if stood for seed.
Tithes were normally paid to the rector of a parish who may be a resident incumbent or an ecclesiastical appropriator such as a bishop, prior, or prioress. Without a resident rector, the vicar could conduct parochial services. The rector received the great tithes levied on corn, grain, hay and wood, while the vicar received the small tithes.

Growing discontent with the tithe

The tithe was an unpopular tax. The reasons for this are many and discussed in detail by Evans (1976). Tithe owners had the right to enter farms to exact their claim. This would consist of the tenth pig, sheep or cow, tenth sheaf of corn, and even the tenth pale of milk (Evans, 1993). Even if the parish was compact and flat the problems of collecting the tithe were considerable. They were virtually insurmountable in large mountainous parishes far from the nearest market where produce could be sold. Often the farmer could not remove produce from the field until the tithe owner's agent had collected his tenth. Delays in collection could spell disaster for the farmers as bad weather could ruin his crop. Even if the farmer could remove his nine tenths, he could not plough or set to pasture his field until the tithe owner appeared. The parish priest was often seen as an avaricious cleric, harassing farmers at harvest time but putting nothing back in to the farming business (Kain, 1988).
Tithes were attacked as a hindrance to improving profitability. As tithe payments were based on gross rather than net produce, they hit those on poorer land harder where investment was necessary. Although the price of farm produce fell after the Napoleonic Wars, many tithe owners still collected their tithes in full. Political economists felt that this was a disincentive to investment and an obstacle to improvement. Farmers were a beleaguered group, claiming to be oppressed by landlords, harassed by labourers and in conflict with the urban masses demanding cheap food (Kain and Prince 1985). The Tithe Commutation Act was enacted during a period of agricultural depression. Between 1820 and 1836 select committees heard evidence of distress in rural areas, where farmers were overtaxed and oppressed by poor-rate assessments and tithes. As Parliament consisted very largely of landowners, such evidence of inequality between farmers and industrialists did not go unnoticed. There were agricultural disturbances in the south of England in 1830-31. Farmers and landowners blamed the tithe to deflect protests by agricultural labourers for higher wages. Between sixty and seventy 'Swing' disturbances centred on the payment of tithes. Riots became more anti-clerical as Bishops voted against reform. Change seemed inevitable as even the Church began to move towards reform to maintain its paternal function within the parish and avoid disestablishment. The situation had deteriorated to such an extent that the government in the nineteenth century had to take action.
In 1836 tithes were still payable in most of parishes within England and Wales. The government of the day decided to commute the tithes, substituting money payments for payments in kind throughout the country. The commuted rent-charge was based on the actual value of tithes paid by the parish to the tithe owner during the seven years to 1836 and adjusted annually thereafter in line with the market prices of wheat, barley and oats. The possibility of future adjustment was achieved by calculating how much wheat, barley and oats the estimated rent-charge could purchase at the average national price for those seven years, if the money had been spent equally on each type of grain. Once the global tithe payment payable by the parish to the tithe owner had been agreed, surveyors would apportion the payment amongst the landowners according to the estimated value of

their fields. An accurate survey of agricultural land was essential for the smooth commutation of the tithe. Little is known of the method employed by valuers or surveyors. Landowners could choose to have sums apportioned in several ways. It could be apportioned property-by-property or field-by-field. Whatever method of apportionment was adopted, the apportionment was recorded on a map and schedule.

The Tithe Commutation Act thus marked the commencement of a series of combined mapping and valuation surveys conducted between 1836 and 1850. They represent a comprehensive inventory of agricultural land in over 11,000 parishes and constituted the largest systematic survey of land use and occupation since the Domesday Book of the Eleventh Century. The survey's detailed maps of landholdings are cross-referenced to tables that list each field, its owner, tenant, acreage, state of cultivation and the amount to be paid as tithe rent-charge (Fig.1).

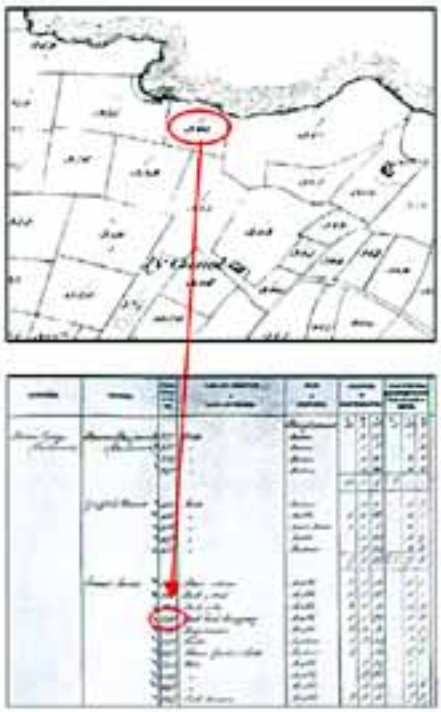
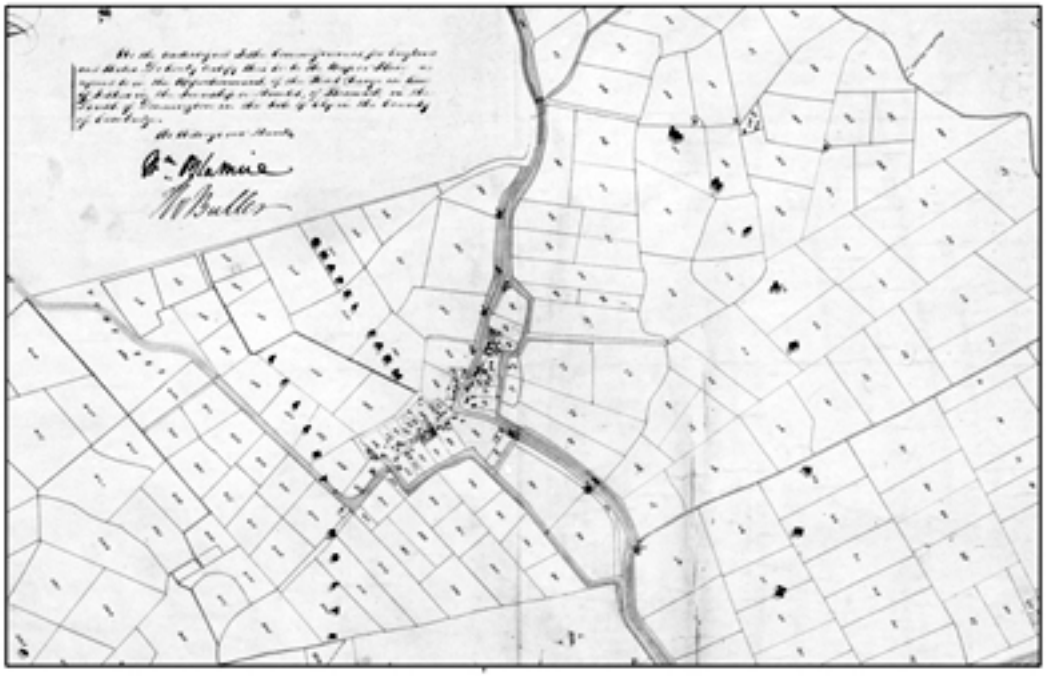
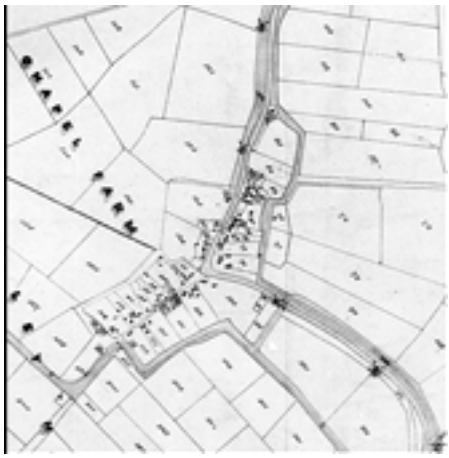


Figure 1. Extract from tithe map showing unique field value relating to entry in the apportionment for the same parish – a Victorian GIS?

Because the Tithe Survey contains so much information, historians and geographers have used it extensively for a number of different avenues of research. Using the tithe rent charge as a surrogate indicator of agricultural land value has been examined in detail by Pearson and Collier (1998 and 2002). Contemporary accounts contained within the accompanying tithe files demonstrate that the surveyors and valuers were very careful in their apportionment of the tithe rent charge. Indeed, there is reassuring evidence that the surveys were carried out by local people who were familiar with the farming practices of the area. Tithe surveyors and valuers were very conscious of the variable quality of the land and concerned that this be reflected in the global tithe rent-charge for each parish. We can only assume that similar sensitivity is shown in his apportionment of the tithe rent-charge on a field-by-field basis. That the parishioners provided little opposition to the apportionment at appeal meetings suggests that the valuation process was successful. We must accept, however, that any analysis of the state of cultivation and the productivity of the land as indicated by the tithe rent-charge must ultimately rest on these assumptions. The surveyor and valuer were

primarily concerned with the survey and allocation of rent-charges within the parish. It is unlikely that they contemplated the information from a geographical point of view. Though the tithe maps are rich in detail (see Figures 2a and 2b) many of the maps presented later in this paper, derived from the tithe apportionment data, are in a form that the surveyor never saw himself. When we consider the pattern of rural settlement as revealed by the tithe surveys, we should be mindful that they were never intended to support such analysis.





Figures 2a and 2b. Though quite plain, tithe maps offer clean and highly legible examples of cartography. The linework is very fine and the shadow effect of the lettering on this extract aids clarity and adds a visual hierarchy. Note the depiction of ‘windmills’ on the drainage channels using an effective mimetic symbol (Images courtesy of the National Archives, Kew).

Methodology

The main software requirements were met by Environmental Systems Research Institute's (ESRI) ArcGIS as it possesses sufficient data input, digitizing, editing and analysis capabilities for the initial map production and exploratory analysis. ArcGIS is one of the most widely used systems in the world, being ubiquitous in higher educational establishments and lay at the heart of most linking components that made up a larger 'system' used for the purposes of this study. Its user interface

is now more embedded within the Windows environment and thus offers a more intuitive introduction to GIS software than has hitherto been the case (See Fig. 3).

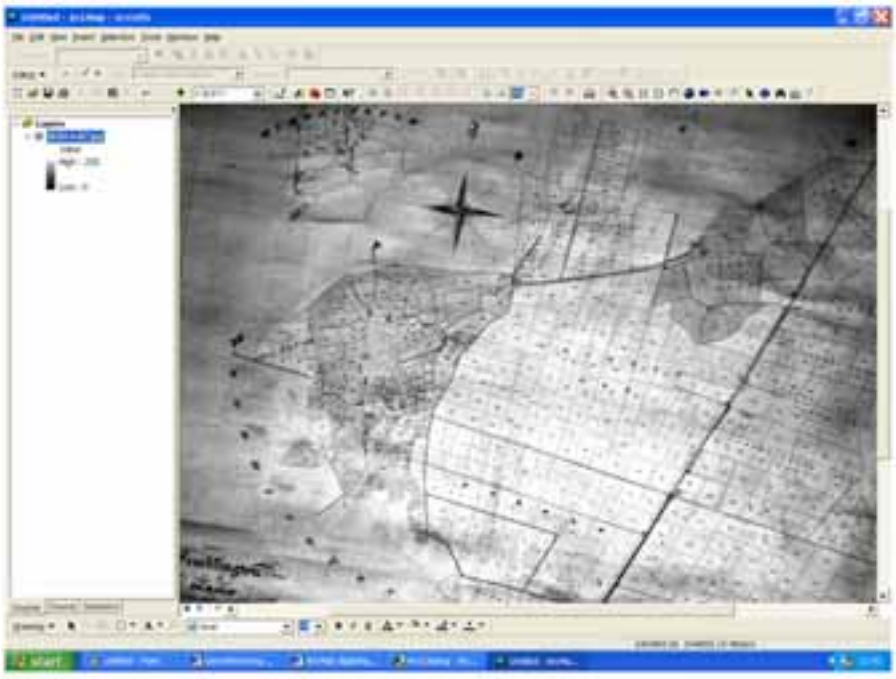


Figure 3. Screenshot of ESRI's ArcMap module that supports cartographic design and data input.

The GIS (sensu lato) was formed by 'loose coupling' ArcGIS and the packages used for data capture and processing, statistical analysis, multi-level modelling and cartographic design.

Data Capture

If the aim of the study had been to examine the quantitative and qualitative accuracy of the data sources then clearly the original maps would have to be digitized. Such a method would satisfy those researchers wishing to work on digital facsimiles of the originals that honour their inherent inaccuracies due to paper distortion and/or cartographic error. However, in a study that attempts to use the analytical and integrative capabilities of GIS as part of a geographical and historical study, the spatial compatibility of primary and secondary sources is of primary concern.

Georeferencing and Digitizing the Tithe Map Images

Digital images taken of the tithe maps using a high resolution digital camera were acquired from the National Archives at Kew, London. In order to use the tithe data in conjunction with our other spatial data, we georeferenced them to map coordinate system of Great Britain (National Grid). Georeferencing the raster images was carried out using existing spatial data (target data) in the form of the parish boundaries supplied by the Ordnance Survey of Great Britain, digitized from maps at a scale of 1:2,500 (larger scale than the tithe maps). The parish boundaries were recognisable on both the tithe map and the OS maps. For each tithe map a series of control points were identified and used to build a polynomial transformation to convert the photographic images from their existing location to the spatially correct location. The

connection between one control point on the raster dataset (the “from point”) and the corresponding control point on the aligned target data (the “to point”) are called links (Fig. 4).

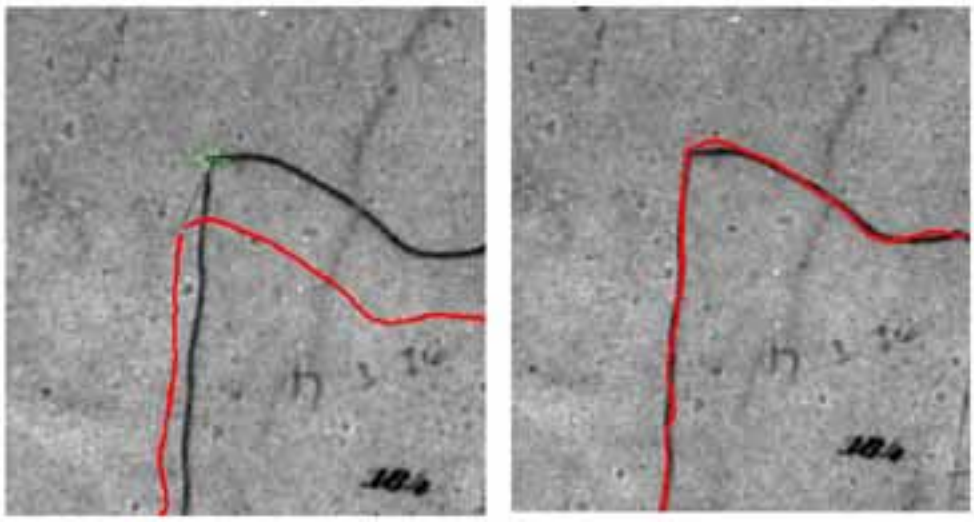


Figure 4. Georeferencing the tithe map to the parish boundary supplied by Ordnance Survey.
The image on the left shows a ‘link’ or control point having been identified prior to transformation.
The image on the right shows the same location after transformation.

The number of links needed depended on the complexity of the polynomial transformation necessary to transform the raster dataset to map coordinates. However, adding more links did not necessarily yield a better registration. If possible, links were spread out over the entire map rather than concentrating them in one area. Typically, having at least one link near each corner of the raster image produced adequate results. First-order transformations handled most of the georeferencing requirements. Transformations higher than third order were rarely needed.

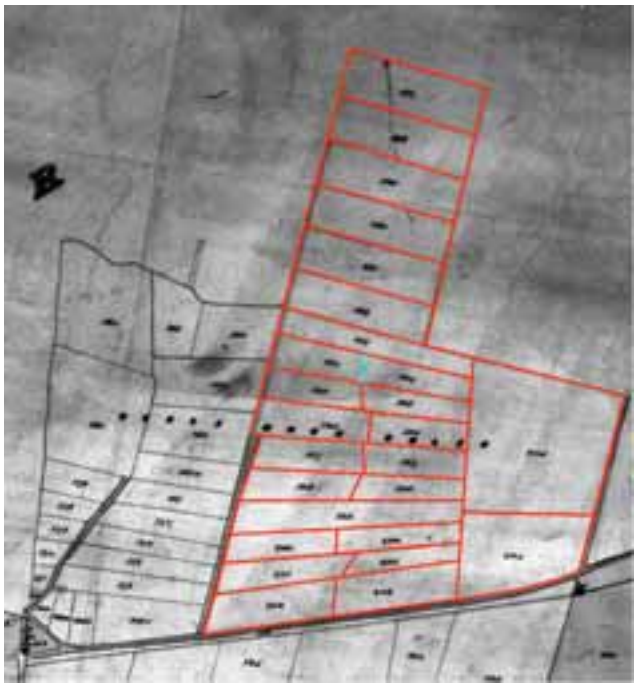


Figure 5. Having transformed the tithe map image, head-up digitizing could begin.

Having transformed the tithe map images, digitizing could commence using a predefined coordinate system and projection – National Grid of Great Britain. Tithe map linework was digitized from screen by careful tracing of the transformed images (Figure 5). Data was initially captured as lines and later transformed into polygons using specific topological rules (no overlapping polygons, dangling lines or pseudo lines).

Output

Once the tithe maps have been digitized, the attribute data can be joined to them. The apportionment values were entered using Oracle with specially designed forms ensuring as much consistency as possible. The greatest value of the tithe maps lies in the richness of their qualitative data and one of the immediate benefits of having the tithe data in a GIS is the ability to display the data flexibly. Varying the classification intervals, colours sequences and adjusting scale are no longer time consuming and error prone tasks. Information on the 'state of cultivation', tithe rent-charge and land tenure can be displayed very effectively.

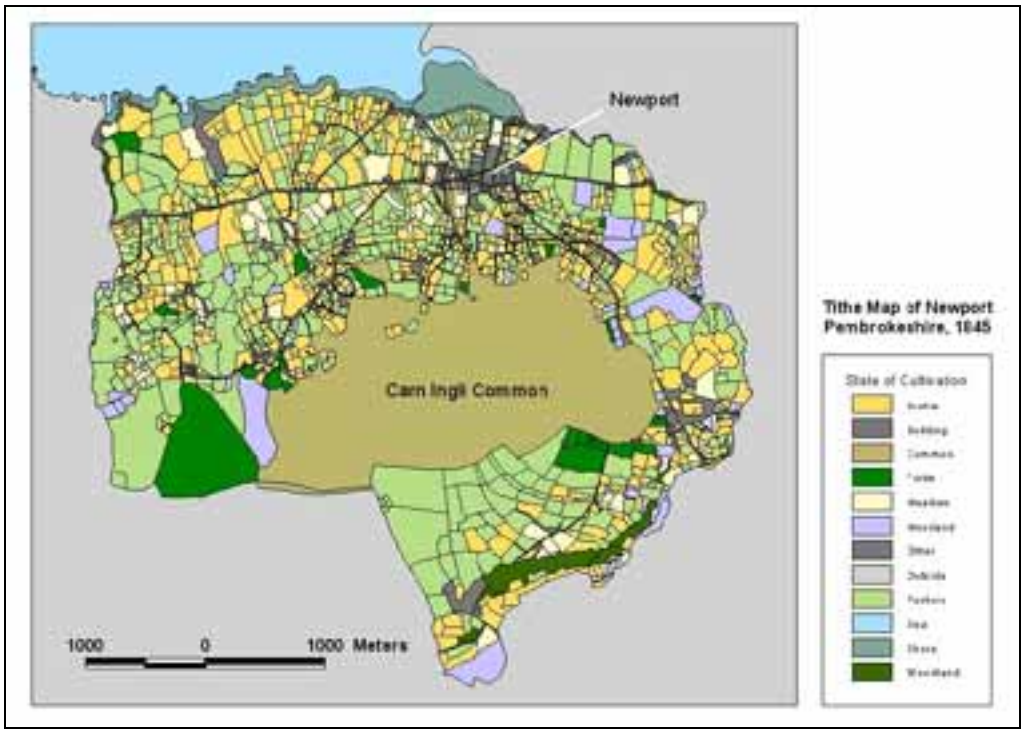


Figure 6. The State of Cultivation at Newport Pembrokeshire, Wales. The pattern of landuse demonstrates a reliance on arable agriculture which has now largely disappeared.

Figure 6 therefore provides a very clear picture of the distribution and pattern of agricultural land use as classified in the 'state of cultivation' column in the apportionment. Examination of the land use is made difficult by the broad definitions of land use given by the Commission to the tithe surveyors and also the subsequent variations in their interpretation of them. What constitutes 'arable' or 'pasture' varied from place to place and differs from modern interpretations. According to the tithe commissioners, those lands that were ploughed within the previous three years for crops or fallow were to be classed as arable. Those lands not ploughed were to be classed as grass. What constitutes 'pasture' or 'arable' is therefore not unequivocal. The distinction between permanent grassland and rotation grasses is also not clear-cut.

This varied from surveyor to surveyor. Indeed, in the Fenlands of Cambridgeshire there is clear inconsistency regarding the use of terms such as ‘arable’, ‘fen’ and ‘up and down’. These terms are used according to the parish within which the survey was conducted but appear to be synonymous for newly drained land that has recently been brought into cultivation . These deficiencies must be borne in mind when we consider the land use map. Nevertheless, much can be gained by viewing such patterns if we are to reconstruct past agricultural landscapes.

The tithe rent charge payment can be taken as a surrogate measure of productivity. Apportionment of the rent charge depended on accurate valuation of each field. Therefore, when we view maps of rent charge per acre we can immediately appreciate the spatial variation in productivity and begin to explore likely explanations for the patterns we see. The Fenlands in Cambridgeshire demonstrate clear contrasts between areas of relative high and low productivity (see Figure 7).

Figure 7. This example shows the rent charge per acre of over 7,000 agricultural fields. Other data can be added, such as main drains, water pumps and contours to aid interpretation.

The patterns of rent-charge do appear to confirm that the apportionment of rent-charge was not random. The map clearly shows a marked decay in rent-charge per acre with increasing distance from the main village centres. This pattern is typical of most of the tithe maps that have been digitized. However, whilst broad similarities can be drawn between parishes of different parts of the country, it is the explanation of the variation that the unique nature of the individual geographies comes through. The pattern of variation in rent-charge of the fenlands appears to correlate in-

versely with the distance of fields from the water pumps and the regularity of the field shape. By the mid-nineteenth century, drainage of this part of the fens had not yet provided the well drained, fertile soils that became so productive by the end of the century. We see a landscape undergoing transformation on a major scale.

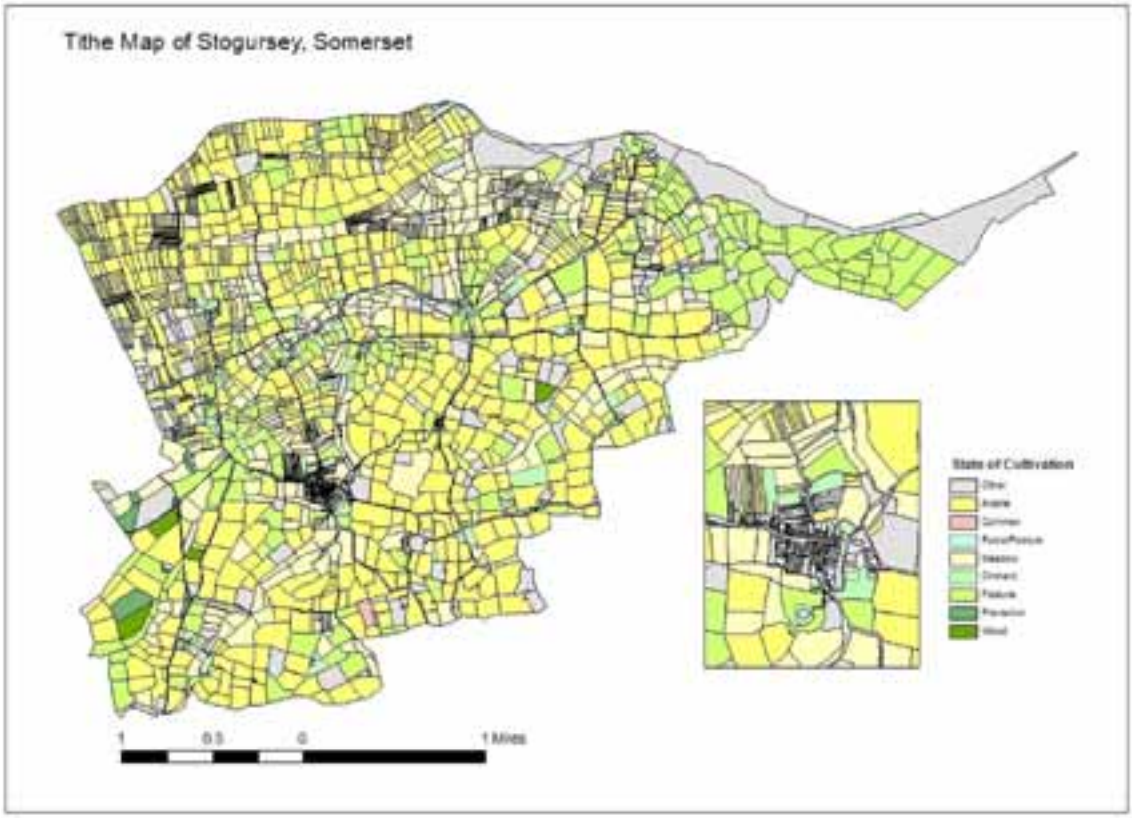


Figure 8. Tithe map of Stogursey, Somerset. Relics of open field systems and flood plain meadowlands remind us of the medieval origins of the nineteenth-century landscape.

Many tithe maps preserve features more familiar to the medieval landscape. Indeed, many tithe maps have been used as anchor points for retrospective studies of landscape development. Figure 8 shows how field form varies within a parish. The regularity of the consolidated, enclosed fields of the majority of the parish contrast markedly with the pockets of narrow strips in the north west of the parish and in the immediate vicinity of the village. Enclosure of the open fields in may parts of England and Wales was a gradual process brought about by the purchase of land by major landowners. Once purchase of neighbouring strips was complete, re-alignment of the fields produced a much more rectangular pattern. Further evidence of the progression of this process is provided in the tithe maps through the landownership and tenancy patterns. Figure 9 shows a large area of Pembrokeshire, Wales where the process of land consolidation had almost entirely eliminated the medieval open field system of land tenure. The agriculturally rich areas of the country had undergone major changes in landholding patterns and the digital maps of the tithes provides us with the opportunity to view these changes.

Other data sources

Data sources that might throw light on explaining the productivity of each field have been incorporated within the dataset where possible. The Census of 1841 is a well-used source for details on individuals and households that provides a crucial insight into the demographic and cultural characteristics of the farming community. Altitude, slope and aspect are generally regarded as a major

factor in determining agricultural landuse and productivity. Ordnance Survey height data is available as low density 50 metre resolution in ESRI Ascii grid format or higher resolution/accuracy 10 metre in the same format. The name of these data types is OS Land-Form PANORAMA DTM 1:50,000 and OS Land-Form PROFILE DTM 1:10000 respectively. Slope and aspect were calculated using the relevant algorithms within 3D Analyst component within ArcGIS. Information on soil was derived from maps published by the Soil Survey of England and Wales.

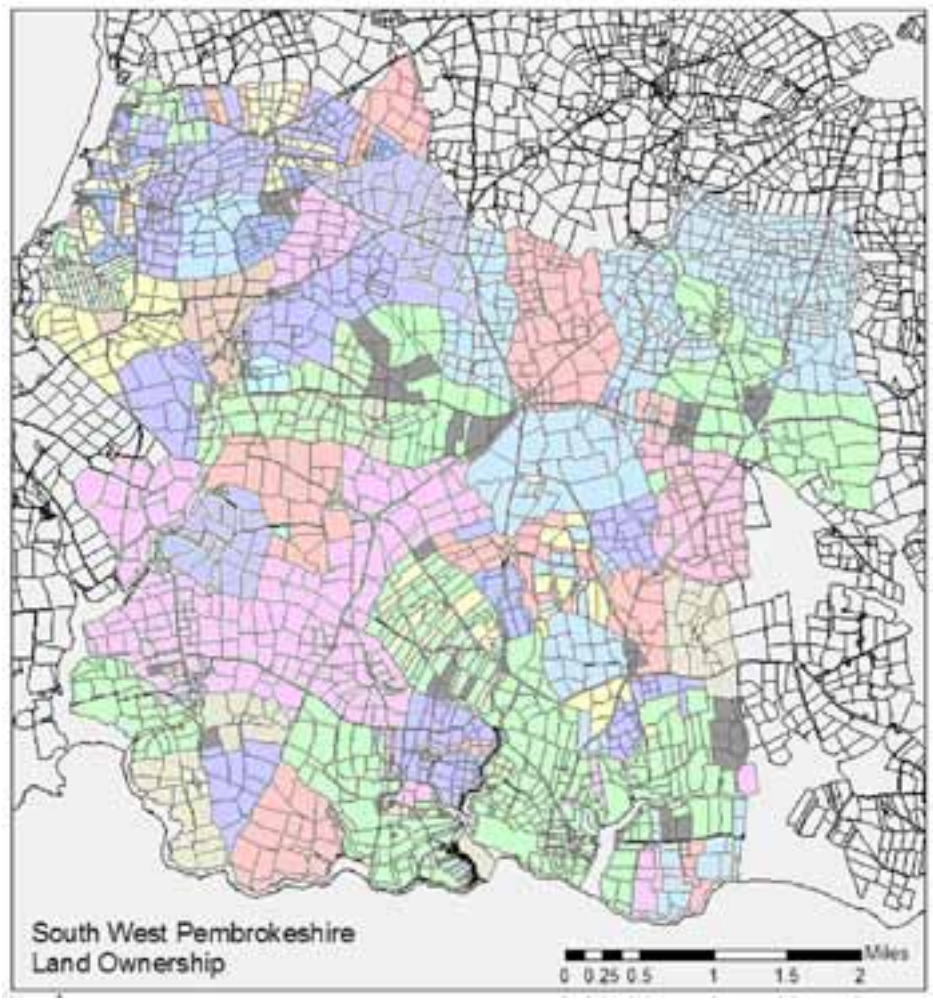


Figure 9. South west Pembrokeshire, Wales. Landownership is a fundamental but 'hidden' part of the agricultural landscape.. Tithe maps is digital form allow usto map it for the first time.

The distances of each field to its nearest settlement was calculated using ArcGIS, having first identified settlements on the original tithe maps. Euclidian distances were used as the detail of the actual route that people took is virtually impossible to replicate. For the Fenland area of Cambridgeshire, the distance to each water drainage pump was also calculated.

There are difficulties in using modern data sources such as altitude for examining past landscapes. Soil quality will have changed over time due to the continuous cultivation of the land and, in the case of the Fenland, the land level has dramatically reduced due to the constant drainage of the land. In places, the altitude of the Fens has reduced by as much as 4 metres. Nevertheless, though absolute values may have changed, their relative values are unlikely to have changed significantly.

Analysis: A case study of the Parish of Newport, Pembrokeshire.

It is perhaps useful at this point to restate the primary aim of the research which is to assess the relative significance of landowner, occupant and natural resource endowments on agricultural productivity as well as identifying and quantifying how these factors interact in different spatial contexts. The tithe rent-charge per acre demonstrates a fascinating pattern that appears to correlate quite closely with topographic variation (Figure 10). However, if we hold all environmental constraints equal, what influence did the landownership and tenancy pattern have on agricultural productivity?

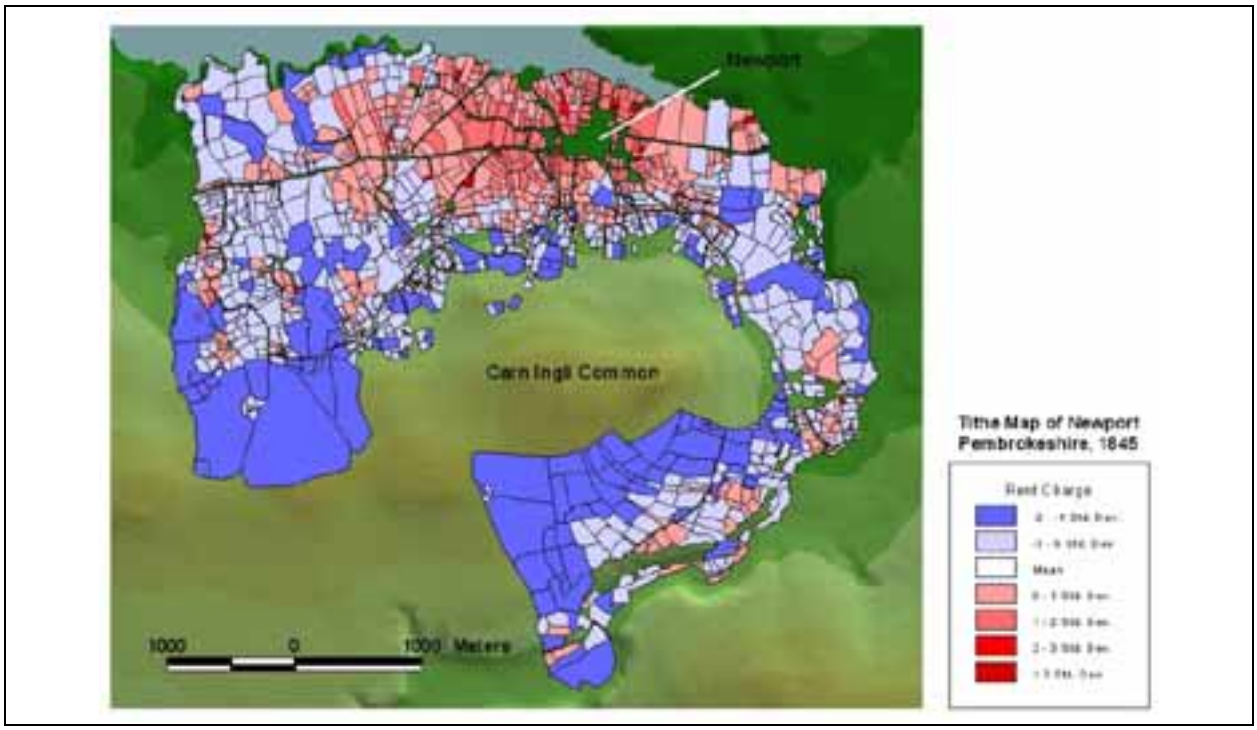


Figure 10. Pattern of tithe rent-charge of Newport Pembrokeshire in relation to altitude.

Analysis of the data employed the latest spatial and statistical modelling techniques. Multilevel modelling has proved to be an effective tool in the analysis of various aspects of the social sciences where hierarchical relationships exist within data (see Twigg *et al*, 2000). For example, multilevel modelling has been used in studies that attempt to explain variation in people's educational attainment (Yang *et al*, 2002) where the influence of the individual, the class teacher, the school, and the education authority can be statistically measured.

Applying traditional ordinary least squares approaches to the data would be relatively inefficient and ineffective. We would first have to decide whether to analyze statistical significance for owners, occupants, or fields. Analyzing for fields would require calculating mean values for each landowner and environmental factor; analyzing for owners would require mean values for each occupant and environmental factor; and so forth. In each case, the process of analysis would eliminate precisely the geographic variation and the geographical relationships we are trying to understand. By using multilevel modelling, it is the nested relationships between individual fields, occupants and landowners that are examined in order to assess the significance of each factor in determining a field's productivity.

Multilevel Modelling

The need to recognise hierarchical data structures where they exist has been the main catalyst in the development of multilevel modelling. School education can be used as an appropriate example of a population with a multilevel structure. The education system has a typical hierarchical structure with pupils learning in classes, classes being taught within schools and schools being administered by education authorities or school boards. Such a system fits a multilevel structure with pupils assigned to level 1, classes to level 2, schools to level 3 and authorities to level 4. Units within one level are viewed as being nested within units at the next highest level. Each of these levels may be a factor in determining the performance of a child. We would assume that it is at the level of the individual pupil that most of the variation can be explained and that the impact of the other levels will decrease as one goes up the hierarchy. Multi-level analysis would give us an indication of the statistical significance of each level on the performance of the child. Similarly, taking our tithe survey, the level-1 units can be viewed as individual fields that nest into two sets of overlapping level-2 units, that is occupants and the owners, forming what is known as cross-classified multilevel structure as demonstrated in the following analysis (Figure 11) (Goldstein, 1995). If we are to measure agricultural productivity as indicated by the tithe rent-charge per acre we have to examine how this structure affects the measurement of interest. Theoretically, if landownership affects the level of productivity, then tithe rent-charges should vary between landowners. This means that occupants of land owned by the same landowner should be more alike, on average, than occupants of other owners' land. A key aim of this part of the analysis is to determine whether certain landowners are more effective than others in promoting agricultural productivity, taking into account variations in the environmental conditions of the land.

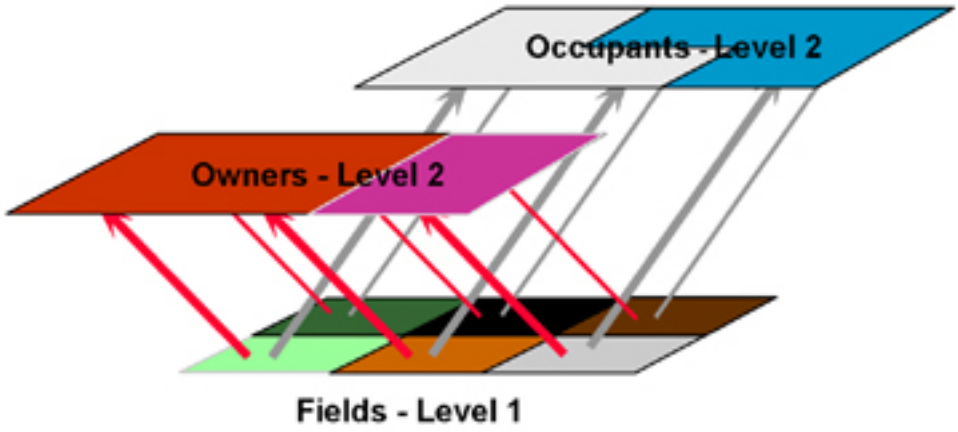


Figure 11. Cross-classified multilevel structure.

The results of multilevel analyses were estimated using the Ml*n* software package. Table 1 provides summary statistics for the model. Model 1 is a two-level model where fields (level 1) are nested within occupants (level 2), whereas fields are nested within owners (level 2) in Model 2. Both models include a number of predictors (logged acreage, height, slope, distance from Newport and land uses) in an attempt to explain the logged tithe rent-charge as used for exploratory single-level regression models. The constant is allowed to vary at both levels one and two (Jones, 1991) and thus two variances are estimated for both models: fields and occupants in Model 1, and fields and owners in Model 2. The estimates for all the fixed terms in Models 1 and 2 are statistically

significant with the exception of the estimate for the contrast term for field under clover, and stable for both models.

It is the interpretation of the random terms that is important. The variation in tithe-rent charge between occupants is estimated as 0.008 in Model 1 and as 0.005 for owners in Model 2. These level-2 variations are both considerable and statistically significant. It is worth noting that there is greater variation in rent for occupants (Model 1) than that for owners (Model 2), and accounts for 19% and 11% respectively. However, the majority of the variation (over 80%) is associated with individual fields in both cases.

	Model 1	**Model 2**	**Model 3**
	Estimate (Standard Error)	**Estimate (Standard Error)**	**Estimate (Standard Error)**
Fixed Terms			
Constant	1.72	1.73	1.75
Logged Acres	-0.24(0.01)	-0.26(0.01)	-0.26(0.02)
Height	-0.002(0.000)*	-0.002(0.000)*	-0.002(0.000)*
Slope	-0.007(0.001)	-0.005(0.001)	-0.006(0.001)
Distance	0.00003(0.000)*	0.00004(0.000)*	0.00004(0.000)*
Mixed Arable	-0.06(0.03)	-0.06(0.03)	-0.06(0.03)
Buildings	0.11(0.02)	0.10(0.02)	0.11(0.02)
Other Land use	-0.10(0.03)	-0.10(0.03)	-0.12(0.03)
Clover	0.02(0.05)	0.02(0.05)	0.02(0.05)
Furze	-0.47(0.04)	-0.48(0.04)	-0.46(0.05)
Meadow	0.18(0.02)	0.18(0.02)	0.17(0.02)
Moor	-0.26(0.03)	-0.24(0.03)	-0.23(0.03)
Pasture	-0.03(0.01)	-0.04(0.01)	-0.05(0.01)
Mixed Pasture	-0.24(0.05)	-0.28(0.05)	-0.29(0.05)
Random Terms			
Level 1: Field			
Variance: Constant	0.034(0.001)	0.04(0.001)	0.034(0.002)
Level 2: Occupants			
Variance: Constant	0.008(0.002)	n/a	0.005(0.002)
Level 2: Owners			
Variance: Constant	n/a	0.005(0.002)	0.004(0.002)

Table 1. Results of multilevel analysis

In an attempt to *simultaneously* assess the contribution of both sets of level-2 units (that is occupants and owners), a cross-classified 2-level multilevel model, was also fitted. The fixed terms associated with the level-1 predictors in Model 3 are almost exactly the same as those estimated for Models 1 and 2 and can be interpreted in exactly the same way. It is the estimates associated with the random terms of Model 3 that are interesting. The variation in rent associated with fields (level 1) is estimated as 0.034 and is the same as that estimated for Model 1 and close to that for Model 2, and accounts for 79% of the total variation in the tithe-rent. The estimated variance for occupants (level 2) and owners (also level 2) are close in value (0.005 compared to 0.004), with 12% of

the total variation in rent-charge being associated with occupants and 9% being associated with owners. There is a considerable (three-eighths) reduction in the variation in rent-charge between occupants having fitted the cross-classified model (Model 3 compared to Model 1). In conclusion it appears that variations in tithe-rent is greater and more considerable for occupants than owners having allowed for a number of level-1 predictors in the fixed part of models. It seems that the occupant rather than the owner provides a slightly greater source of contextual variation in the tithe rent-charge as one would expect. The occupant does appear to be an influential level suggesting that the holdings varied in their success at coping with environmental conditions.

It is difficult to draw too many conclusions from such statistical analysis given the rather narrow geographical extent of the study area. However, the results are given some credence by Howell's observation that in Pembrokeshire the efforts of the larger landowners were probably largely unsuccessful. Furthermore, it may have been that the minor gentry and those large freeholders and tenant farmers below them did most to advance the techniques of agriculture by dint of patient trial and error. Expansion of the analysis to other parishes in England and Wales is underway and will clearly improve the validity of the results and help to identify the varying success of farmers in adapting to the physical conditions of the area.

Concluding remarks

To restate our theoretical assumption, if landowners influenced productivity, then Tithe rent charges should vary between landowners when all other constraints are held equal. Our research has hitherto provided some tantalising results. Results suggest that environmental conditions were perhaps overwhelmingly important in shaping agriculture and in preventing an agricultural revolution in southwest Wales and that only minor differences separated the productivity of land on improvers' large estates and on smallholdings. If this is in fact the case, then this is powerful new evidence that landlords who criticized farmers (and scholars who side with them) got it wrong. An agricultural revolution was virtually impossible in many marginal parts of England and Wales not because farmers were conservative and ignorant or because they lacked capital but because the land's natural endowments were so poor. Drawing this conclusion from a fuller detailed analysis of new data gathered for other parts of the country will be a serious contribution to historical scholarship.

Though this project demonstrates the clear benefits of digitizing historical maps to facilitate analysis, it is to the Victorian surveyors and valuers that we owe our largest debt. Furthermore, whilst the planimetric accuracy of the tithe maps is clearly significant, it is in their qualitative accuracy that their true value can be appreciated.

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