The Feudal Origins of Manorial Prosperity:
Social Interactions in 11^{th}-century England

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Abstract

Does the prosperity of medieval manors depend on their position in the feudal system? How large are these effects? And what are the economic mechanisms behind it? Using Domesday Book, a unique country-wide survey conducted by William the Conqueror, we reinterpret the 11^{th}-century English feudal system as a network in which manors are linked to one another based on their common ownership structure. Both a reduced-form and a more structural approach reveal the existence of external economies of scale: manorial prosperity was closely intertwined with the fortune of feudal peers, even after including rich agricultural and geographic controls.

Keywords: Domesday Book, feudalism, medieval economic history, social interactions

JEL codes: L14, N33, O33

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1 Introduction

The most characteristic feature of the civilization of feudal Europe was the network of ties of dependence, extending from top to bottom of the social scale.

— Marc Bloch in *Feudal Society* (1968, 282)

Few authors have described the pervasive nature of feudalism as vividly as French historian Marc Bloch in his seminal work. For centuries, feudalism was one of the most prominent and salient features of European economies. Nonetheless, its impact on microeconomic decision making, in particular during the High Middle Ages, remains empirically illusive. This paper presents first quantitative evidence on the economy-wide significance of the 11^{th}-century English feudal system, facilitating agricultural cooperation, and information-sharing among feudal landowners and their managers.

The possibility of such interdependencies between Anglo-Norman manors has been suggested before by medieval historians. For instance, Wareham (2005, 107) hypothesizes that inter-manorial connections, among other factors, could have led to efficiency gains in the production of grain, livestock, and other agricultural produce, "thereby leading to a rise in the valuation of the estates relative to their counterparts". There are credible reasons to believe this was indeed the case in the High Middle Ages. Scholars working on later periods have found micro-level evidence on economic cooperation across English manors with respect to cattle management and transportation.[1] Furthermore, historical reconstructions of agrarian productivity have highlighted the importance of inter-manorial coordination in management decisions (Biddick & Bijleveld, 1991; Karakacili, 2004). Such interactions plausibly led to information transfers along the feudal network. In his influential work on English medieval agriculture, Campbell (2006, 421) writes that "much information and advice must also have been exchanged between manors belonging to the same estate, and estates belonging to the same religious order".

Empirical evidence on the High Middle Ages is limited, however. The most comprehensive quantitative source on this period is Domesday Book, the kingdom-wide

[1] This is mostly based on ecclesiastical manorial accounts from the Late Middle Ages. Biddick (1989, 86) documents how Peterborough Abbey, in the early 14^{th} century, used inter-manorial transfers to and from specialized breeding manors to correct for cattle shortages, and surplus elsewhere on the estate. Also, Slavin (2012, 107) highlights how 14^{th}-century Norwich Cathedral Priory authorities established cooperation across its respective manors in the transportation of their agricultural produce.

inquest of King William I into the economic state of Anglo-Norman England. However, all econometric research on this source ignores the rich patterns of feudal landownership, instead modelling the manors as independent entities.[2] In the ensuing analysis, we take a different approach and allow for two plausible interaction mechanisms: scale and productivity spillovers.[3] In the former, production costs are cut by agglomeration effects, such as the efficiency gains arising from large-scale transport of agricultural produce among feudal peers. The latter are interpreted as productivity gains through common experiences with regard to successful management practices. Both mechanisms are reminiscent of Marshall's (1890) external economies of scale, but now applied to feudal, instead of geographic, distance.

To disentangle these two mechanisms, we reinterpret the feudal system as a network in which manors are linked to one another based on their common ownership structure.[4] Making use of this feudal network, our empirical interactions model provides a rich, yet parsimonious, description of the interdependencies between manors, while also controlling for spatial autocorrelation through the geographic network. We argue that the sparse, non-overlapping nature of both networks allows us to separately identify the two economic mechanisms at hand, and to assess the relative contributions of feudalism and location. To construct the feudal network, we make use of the Hull Domesday Project database (Palmer, 2010), which provides the most up-to-date identification of landowners in 11$^{\text{th}}$-century England. Identification of manors' tenants-in-chief and lords allows us to link manors to one another based on their common ownership structure. The database also contains the monetary value, resources, and location of each manor. The location is used to construct the geographic network, which allows us to control for spatial clustering. In addition, we impute environmental determinants of manorial wealth, such as agricultural suitability from the Global Agro-Ecological Zones project (Fischer et al., 2012), using geographic information system (GIS) methods.

[2]For example, see McDonald and Snooks (1986), McDonald (1998), McDonald (2015), and Walker (2015).

[3]It is worth noting that these mechanisms might also capture certain economies of scope, such as crop specialization across peers. However, the nature of the Domesday Book data does not allow for a disentanglement of scale and scope effects. In this regard, our interpretation of economies of scale is necessarily rather broad.

[4]In this paper, we interpret feudalism as an institutionalized network of interactions among landowners. It goes without saying that this interpretation is rather specific, given the all-encompassing economic, legal, military, and social nature of the feudal system.

Our results reveal that a manor's prosperity, as expressed in terms of its value, was closely intertwined with the fortune of its feudal peers.[5] More specifically, this paper commences by presenting reduced-form evidence in the form of high correlations in capital and labor productivity among manors which were connected through feudal ownership. Next, we conduct a more structural approach, in which we model the economic nature behind these correlations by allowing for external economies of scale. This allows for the quantification of the aforementioned roles of spillovers in agricultural cooperation and human capital, respectively. We find that both mechanisms played a significant role in High Medieval agriculture, although the productivity spill-overs clearly dominate the scale spill-overs in terms of economic importance. Furthermore, we report evidence for similar external economies of scale through the geographic network of neighboring agricultural producers. Multiple sensitivity checks are presented to account for the possibility of network endogeneity, and for the obscurities in Domesday Book, highlighted by decades of Domesday scholarship.

Our contribution to the literature is threefold. First, we reinterpret and model the feudal system as an economy-wide network of interactions that impacts economic behavior at the micro-level. In doing so, we establish the existence of feudal coordination in the management of agricultural activities in the England of William the Conqueror. This sheds new light on the microeconomic decision-making of medieval economic agents, which is challenging to reconstruct (for example, see Stone, 2005). Our results underline the pervasive impact of institutional interactions on manors' agricultural production decisions. From a broader perspective, we also contribute to the strand of research on how socioeconomic and political networks played a role in economic history. It is now widely recognized that such networks are central to the understanding of historical interactions in trade, business, and the diffusion of knowledge and technologies (see the overview by Esteves & Mesevage, 2019 and references therein). Although being a prime example of a network in economic history, no formal econometric analysis has ever been undertaken on feudal interactions.

Second, our analysis expands the understanding of how social interactions and, therefore, the transmission of information played a crucial role in the integration of

[5] We use the terms value, wealth and production interchangeably. In Domesday scholarship, it is commonly accepted that the manorial monetary valuations reflect their productive capacity and are, by extension, a part of the landowners' wealth accumulation. In this context, this paper defines observed productivity as the ratio of a manor's value to its resources.

medieval economies. Specifically, the existence of inter-manorial coordination across the kingdom points to the importance of accounting for institutional features of 11th-century economies, as these could serve to propagate social interactions and knowledge throughout the country. It was long believed that information was scarce in pre-industrial economies, with transaction and information transmission costs being exacerbated by limited means of communication and transport. Over the past decades, however, economic history research has rehabilitated the role of medieval markets and commerce, establishing the idea of a commercial revolution in the long 13th century (for a notable example on England, see Britnell, 1993).[6] Reductions in transaction costs are considered to be an important driver of market activity in medieval times (Hatcher & Bailey, 2001, 155). Nevertheless, it is only when literacy became more widespread in the 13th century, that historical sources started to emerge to document such claims. Indeed, 14th-century purveyance accounts reveal that transport costs were "remarkably low" (Masschaele, 1993, 266).[7] Furthermore, building on 13th-century price data, Clark (2015) has recently emphasized that grain markets were more integrated and efficient than previously thought. Evidence regarding transaction costs in the early periods of the High Middle Ages is more scarce though.[8] Our findings shed first light on the idea that 11th-century transaction costs might not have been as high as previously assumed or, at least, that institutional features could serve to overcome certain communication barriers.

Last, we provide a more nuanced view of medieval institutions. While feudalism might be detrimental for aggregate welfare, it also provided a platform through which common experiences on successful management practices and the efficient exploitation of manors' production factors, be it their lands or their labor, were exchanged through the means of social interactions.[9] Others have successfully shifted attention away from the predominantly pessimist views of medieval institutions. For instance,

[6]This commercialization hypothesis is still subject to academic debate. For a more critical appraisal, see Schneider (2014).

[7]See also the discussion and references in Langdon and Claridge (2011).

[8]An early contribution on the accomplishments in early medieval transport and communication can be found in Leighton (1972). The lack of material for the historian to work with is emphasized, asserting that this period "provides little grist for the scholar's mill" (Leighton, 1972, 10).

[9]In other words, our results do not conflict with either view on feudalism in the aforementioned efficiency debate. Domesday Book only presents information on the seignorial economy and, as a consequence, does not allow for claims on the aggregate welfare effects of feudalism without additional assumptions.

Epstein (1998) famously argues how medieval guilds emerged to provide a framework in which skills and technological innovations could be transferred. Such an argument draws comparisons with our interpretation of feudal interactions, which allow for the transmission of best-practice agricultural techniques. A contrasting view, however, emphasizes the inefficient nature of guilds, giving rise to rent-seeking and other economic growth-deterring behavior (Ogilvie, 2004, 2019). Interestingly, a similar dichotomy lies at the root of the intense debate on whether feudal institutions were an efficient outcome, or rather a rent-seeking construction (for notable examples, see North & Thomas, 1973 and Brenner, 1976, respectively).

Recently, economists have typically adhered to the latter, more negative, appraisal, pointing at the feudal system as the culprit for centuries of limited economic development in medieval Europe. Most notably, Acemoglu and Robinson (2012, 176) claim that feudal institutions "formed the basis for a long period of extractive and slow growth in Europe during the Middle Ages". The main idea is that these institutions were designed to extract wealth from the many peasants to the few elite landholders. The results in this paper provide first evidence on how feudal networks facilitated wealth accumulation of well-connected landowners within the institutional framework of feudalism.

The remainder of the paper is structured as follows. In Section 2, the Domesday Book and its historical background are introduced. Section 3 reappraises previous research on the determinants of manorial prosperity, using said historical source. In Section 4, we subsequently argue for the need to incorporate the feudal network, a key and pervasive feature of the medieval economy, in econometric approaches to economic decision-making during the High Middle Ages. Section 5 provides empirical evidence on the role of both the geographic and feudal network, through reduced-form evidence as well as a more structural approach. Section 6 contains sensitivity analyses. Finally, Section 7 concludes.

2 Domesday Book

2.1 Historical background

The Norman conquest of England was a landmark event in the history of Medieval Europe. Following the death of the childless Anglo-Saxon King Edward the Confessor on 5 January 1066, William, Duke of Normandy, made a claim to the English throne. King Edward was, however, succeeded by Harold, his brother-in-law. This pressed William to gather an invasion fleet of French and Flemish soldiers, which landed in Sussex, southern England, on 28 September. On 14 October 1066, the English army of King Harold, who himself was killed in battle, suffered a decisive defeat to the Norman army. The decades that followed were characterized by a long and difficult period of consolidation. English lordship loyal to the former king were replaced by those who fought alongside William.

The 11$^{\text{th}}$-century England of King William I, later hallmarked as William the Conqueror, was organized by a feudal system in which landowners, i.e. the *tenants-in-chief*, received land directly from the king in return for financial and military support. While this concept of knight service was long believed to be a Norman innovation (Round, 1895, 225-314), it is now established that the Anglo-Norman feudal system was strongly built on the foundations of ownership structures already in place (see Roffe, 2007, ch. 5 for a discussion). These landowners, who comprised both nobility and clerics, could in turn sublease their land to others, i.e. the *lords*, or operate the landholdings themselves. This hierarchical network of landowners played a defining role in the workings of medieval economies. Agricultural activities were organized around the landowners' manors, and were performed by various types of workers. Peasants were typically bound to the land on which they resided, and often to its lords too, to whom they owed labor service.

Almost twenty years after his coronation, William the Conqueror announced an inquiry into the state of affairs in his kingdom. What followed was a remarkable exercise of central administration for its time. The kingdom was divided into (presumably) seven circuits, which were all visited by a team of commissioners. Tenants-in-chief were interrogated on the present, and past, ownership of their holdings, its values, its population, and the available economic resources, such as ploughs and livestock. Before their submission to the Exchequer in Winchester, local boards of four English and four Norman jurors were tasked to verify the landowners' answers.[10] The pervasive nature of the feudal hierarchy presents itself in the structure of the book, which was organized not on a geographic but on a feudal basis (Darby, 1977, 4-9).

The result is a historical document that showcases a uniformity and geographic coverage incomparable to any other historical source in medieval Europe. Due to its definitive character, this 'Book of Winchester' earned the name 'Domesday Book' in the century to come (Harvey, 2014, 271-273).[11] Domesday Book presents researchers with a unique insight into the feudal structure of a medieval society and the functioning of contemporary rural economies. Nevertheless, it should be emphasized that Domesday Book is far from a straightforward document. The original source is recorded in Latin and requires careful translation. Its layout based on the feudal structure makes it challenging to reconstruct the regional character of England's population and agricultural activities. These challenges have brought forth a large literature of Domesday scholarship since the end of the 19$^{\text{th}}$ century.[12] In what follows, we show how these fundamental contributions can be employed to construct a database fit for our econometric interactions model.

2.2 Data description

Domesday database We rely on the work of Palmer (2010) and his team of the Hull Domesday Project (HDP). This data set provides a comprehensive overview of all manors in 1086 England, their resources as well as their value in shillings at the time of the conquest, 1066, and at the time of the inquest, 1086. To achieve this, the recorded resources of all seven circuits were carefully distributed across manors. While other translated and digitized versions of the Domesday Book exist, the HDP database is the only version which is constructed with statistical analysis in mind.

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[10] Not all stages of the data collection process can be easily reconstructed by current-day research. See Harvey (2014) for a comprehensive discussion of the organization of the inquest and its obscurities.

[11] Domesday Book actually consists of two main parts: Great or Exchequer Domesday book, which is the definite version compiled by the Exchequer clercs, and Little Domesday Book, a preliminary and unabbreviated version. The former covers the first six circuits, while the latter contains information on a seventh circuit covering eastern England.

[12] Round (1895) is typically considered to be the founding father of modern Domesday scholarship. The references in this section only serve as an illustration of the vastness of the available literature.

The HDP database also contains a comprehensive list of all Domesday landowners in 1066 and 1086. Importantly, they identified and standardized a majority of the 1086 landholders.[13] In the presence of inconsistent reporting of personal names, a phenomenon which should be expected given the historical nature of the source at hand, this is of crucial importance. In this effort, the Hull team was supported by decades of work by preceding Domesday scholars.[14] It is safe to assume that this is the closest one will ever come to reconstructing a complete feudal system for economic analysis.[15] Nevertheless, it is still worth emphasizing that network mismeasurement and selection bias are important considerations in this context. We will return to these issues in Section 6.2.

Manors' resources Economic activities in English manors around 1086 mainly involved growing crops and raising animals. Domesday Book illustrates that especially arable farming, i.e. the cultivation of crops,[16] was of high importance: the number of ploughteams and ploughs needed to bring the manor to full production capacity received a central place in the inquiry. In contrast, the livestock counts were redacted out of the final version of the Great Domesday Book.[17] In this context, we specify the resources which could explain the variation in wealth across manors.

A first resource important to production was the availability of labor. Domesday Book provides an intricate categorization of laborers depending on their legal status, ranging from the *liberi homines* (free men, not bounded to land) to slaves. Following Walker (2015), we simplify this subdivision by making the distinction between slave

[13]The coverage of the 1066 landowners is incomplete at best. We return to the issue of the 1066 data in Domesday Book in Section 6.2.

[14]A comprehensive list of this literature is supplemented to the electronic version of the database. The impressive work of Keats-Rohan (1999) deserves special credit, as Roffe (2007, 164) describes how she "has identified almost all the holders of land in 1086".

[15]Lowerre (2016, 227), for example, claims that "Palmer's identifications are doubtless among the best and most comprehensive currently available".

[16]Efforts were mainly concentrated on the cultivation of grain (wheat, rye, barley, and oats), with legumes (mostly peas and beans) being less important (Dyer, 2009, 14).

[17]However, due to its difficult-to-quantify nature, the role of husbandry in medieval agriculture remains a contentious topic (for a discussion, see Biddick, 1989, 1-4). The relative importance of crop cultivation is supported by both our, and earlier, empirical analyses for subsamples of Domesday Book for which figures survived (Exeter Domesday Book and Little Domesday Book): livestock contributed little to the Domesday value of the manor (McDonald & Snooks, 1985; Walker, 2015). It might also be that livestock plays a limited role in Domesday Book given the impossibility of Domesday surveyors to assess the animal count's reliability. Because of this, we are bound to follow many traditional historians in the assumption that agricultural performance in the cereal and livestock sectors is highly intertwined.

labor and all other forms of labor.

The high reliability on the cultivation of crops implies that ploughs and land were inputs of high importance. Recent empirical research has highlighted the crucial impact of plough technologies on long-run agricultural productivity (Andersen, Jensen, & Skovsgaard, 2016). Domesday Book records the number of ploughs available at each manor. In addition, both the quantity and quality of its land were essential to the determination of a manor's value. Domesday Book is the only medieval source which casts a light on the amount of arable land, albeit a very oblique one (Campbell, 2006, 386-387). Landowners were asked the extent of their manors, expressed as land for so many ploughs. In theory, this is a straightforward measure of arable land. Despite its simplicity, the ploughlands variable is one of the most disputed pieces of information in Domesday Book, with scholars highlighting inconsistent reporting and the infamous phenomenon of 'overstocking' (i.e. manors where the amount of ploughs exceeds the number of ploughlands). Moreover, little consensus exists on whether the ploughlands should be considered as a measure of land, or rather as a fiscal measure (Roffe, 2007, 203). For the purpose of our analysis, we propose the following way forward. In our main estimates, we take the ploughlands variable at face value in our main estimates. In addition, we conduct a robustness check, in which we assume that land was a perfect complement to the other two key determinants of manor wealth, capital and labor, discarding the need for a land quantity variable.[18]

With respect to the quality of the land involved, we link the locations of the Domesday manors with a contemporary GIS database on the suitability of English lands for agriculture. The former are identified by the Palmer team, with their coordinates being approximated to the nearest kilometre. For the latter, the Global Agro-Ecological Zones (GAEZ) project (Fischer et al., 2012) provides environmental suitability indices for a variety of crops. To approximate 11$^{\text{th}}$-century agricultural conditions as closely as possible, we use the GAEZ classification for barley suitability under the assumption of traditional management, i.e. the usage of only labor inten-

[18] For further discussion, see Section 6.2. Other than ploughlands, Domesday Book also reports meadow, pasture, and woodlands. McDonald and Snooks (1986) use this information as a measure of land in their regional study of the counties of Essex and Wiltshire. These variables are, however, inconsistently reported. Moreover, the heterogeneous use of all kinds of measures make the standardization to a common denominator, such as acres, impossible (see, for example, Darby, 1977, 142, 190). As a result, it is impossible to incorporate these variables into an analysis at the national level.

sive techniques without the application of nutrients, irrigation, or other contemporary techniques.[19]

The relationship between the wealth of feudal landowners and the geological characteristics of their lands is a underresearched topic, despite arguments that 20$^{\text{th}}$-century soil maps are informative of past conditions (for a discussion, see Andersen et al., 2016, 143).[20]

Sample selection Finally, we impose a series of plausible sample conditions. First, as this analysis only concerns landholdings that are economically active, we exclude manors that did not generate any value.[21] In other words, we are solely concerned with economic decisions on the intensive margin, rather than the extensive margin. Second, both labor and capital resources have to be recorded in the data. Likewise, we exclude observations with missing values for the ploughlands variable in our main analysis. Third, a manor may refer to more than one place. For our main analysis, we restrict the sample to single-location manors. Finally, the landowners of about 15% of all manors in Domesday Book are unidentified. As these manors' lords were presumably less important landholders, we assume that these are unique to the manor and, therefore, do not have other possessions. Table 1 presents the number of cases and frequency for each of the sample conditions. The impact of alternative sample selection and identification rules is discussed in Section 6.2. Table A1 in Appendix A presents summary statistics of the main variables for this sample.

[19] We also considered a similar suitability index for wheat cultivation. This index is, however, highly correlated with the measure for barley, and consequently adds little to the analysis.

[20] As Lowerre (2016) recently emphasized, the full richness of the Domesday England's geography has never been utilized in the literature. An exception is the local study of McDonald (1998) on the county of Essex, which found an insignificant connection between manorial efficiency and soil type. However, he only considered soil types and did not address the issue of agricultural suitability. A more recent attempt in this vein can be found in the study of Rossignoli and Trombetta (2021).

[21] In other words, we assume that manors with no value did not generate any income, as is common in empirical research on Domesday Book. It is, however, worth noting that alternative interpretations of the value variable have been furthered in Domesday scholarship. We expand on this issue in Section 6.2.

Table 1: **Sample conditions**

Condition	Cases	Frequency (%)
No value recorded	1,215	6.08
No labor recorded	3,093	15.49
No plough recorded	1,069	5.35
No ploughlands recorded	5,905	29.57
No location determined	1,422	7.12
Multiple locations determined	843	4.22
No ownership	377	1.89

3 Manorial values and resources

Following the majority of pre-existing empirical work on Domesday Book (for the earliest example, see McDonald & Snooks, 1985), we establish the relationship between the value y_i of manor i and its aforementioned resources $\mathbf{x}_i$ (both expressed in logarithms). In addition, $\mathbf{x}_i$ includes county and soil quality dummies. For now, we assume that manors in 11$^{\text{th}}$-century England operated as separate, individual entities, regardless of their position in the feudal system. The following baseline equation can then be estimated using Ordinary Least Squares (OLS),

$$y_i = \alpha + \mathbf{x}_i\boldsymbol{\beta}' + \varepsilon_i, \quad \mathbb{E}[\varepsilon_i \mid \mathbf{X}] = 0, \tag{1}$$

where ε_i can be interpreted as unexplained productivity. The left-hand side of Equation (1) is expressed in shilling prices, in contrast to the right-hand side, which is expressed in quantities. In case of a constant ratio of prices of capital and labor across the Anglo-Norman kingdom, our estimate of $\boldsymbol{\beta}$ is not effected.[22] If one assumes that a manor's value is determined by its agricultural production, it is easy to interpret Equation (1) as a Cobb-Douglas production function, in which $\boldsymbol{\beta}$ then represents output

[22]Another concern here is spurious productivity estimates that could arise when output prices are higher around London. We therefore investigated the relation between a manor's value-to-labor (or value-to-capital) ratio and its distance to London. We found no significant correlation, which suggests that this issue is likely not to be empirically relevant.

elasticities of the respective resources.[23]

Table 2 presents the correlational relationship between the manorial values and the resources recorded in the Domesday Book. Our results can be easily compared with earlier analyses at the local level, such as the ones in McDonald and Snooks (1986) for the counties of Essex and Wiltshire, as well as with the more recent work of Walker (2015), who was the first to estimate a similar relationship at the national level. Just like these studies, we observe a strong relationship between manorial resources and their values. The availability of ploughs as a capital good played a crucial role in determining a manor's economic value in each of the respective specifications. Labor that was not fully bound to the lord's ownership, had a somewhat higher effect on the manorial income than slave labor.[24]

The inclusion of ploughlands as a land quantity measure in specifications (2) and (4) has only a minor impact on the interpretation of our results. This is to be somewhat expected, given the highly collinear nature of the ploughs and ploughlands variables. In addition to previous work, we include a categorical soil quality variable to all our specifications. These contemporaneous estimates of agricultural suitability are adequate in explaining high manorial values, strengthening our prior assertions that the values in Domesday Book represent manorial agricultural activity. The inclusion of county fixed effects in specification (3) and (4), however, appears to absorb most of the geographic environment effect. This explains why our coefficients are relatively comparable to previous estimates that assume a similar, linear relationship.[25]

[23] A common concern here is the endogeneity of the inputs, i.e. when a manor chooses its inputs based on its (unobserved) productivity ε_i, the OLS estimates might become biased. In a context without developed capital markets and where labor was (in many cases) bound to land, however, it can be argued that inputs were relatively fixed in the short run (McDonald & Snooks, 1986, 116). Consequently, we presume that the effects of this so-called simultaneity bias are limited in our context.

[24] In the Cobb-Douglas specification of Equation (1), the sum of the coefficients approximates one, providing evidence for constant returns to scale. We can, therefore, interpret the coefficients of the production factors as their respective income shares. Our results reveal a rather low labor share for the seignorial economy, whereas recent estimates suggest a rather stable labour share level for the entire economy, fluctuating around 0.68 (Humphries & Weisdorf, 2019). This indicates that the feudal economy was highly beneficial to capital owners and largely expropriated the fruits of peasant labor.

[25] Aside from providing a satisfactory way to control for local effects, another advantage of including county fixed effects is that it alleviates concerns of variation in administrative practices across circuits. English counties were grouped in seven circuits with potentially diverging administration practices (see Section 2.1).

Table 2: **Relationship between manorial value and resources (OLS)**

Parameter			**(1)**	**(2)**	**(3)**	**(4)**
Labor: non-slaves		β_1	0.23***	0.24***	0.19***	0.18***
			(0.01)	(0.01)	(0.01)	(0.01)
Labor: slaves		β_2	0.17***	0.14***	0.13***	0.10***
			(0.01)	(0.01)	(0.01)	(0.01)
Capital: ploughs		β_3	0.62***	0.54***	0.66***	0.57***
			(0.01)	(0.02)	(0.01)	(0.02)
Land: ploughlands		β_4		0.12***		0.13***
				(0.01)		(0.01)
Land: suitability	High	β_5	-0.02**	0.04***	-0.02**	-0.01
			(0.01)	(0.01)	(0.01)	(0.01)
	Low	β_6	-0.21***	-0.28***	-0.02*	-0.02*
			(0.01)	(0.01)	(0.01)	(0.01)
Constant		α	-0.25***	0.31***	-0.16***	-0.21***
			(0.01)	(0.01)	(0.02)	(0.02)
County FE					YES	YES
Observations			12,222	9,084	12,222	9,084
R^2			0.72	0.74	0.81	0.84

Note: All variables are in logarithms. The reference category for the land suitability variable is 'moderate'.
Standard errors are in parentheses.
$*** : p < 0.01, ** : p < 0.05, * : p < 0.1$

4 A network approach to feudalism

The importance of the feudal network Notably, an empirical approach, as in Equation (1), foregoes the feudal reality of economies in the High Middle Ages. It has already been emphasized that the seignorial economy was organized on the foundations of the Anglo-Norman feudal system. Manors that shared ownership are likely to have interacted in an economic sense. Indeed, evidence from the Late Middle Ages reveals that feudal peers cooperated closely in various aspects of microeconomic decision-making, such as agricultural activities and the transport of goods, as previously outlined. In other words, interactions among feudal peers were conducive to the integration of manorial economies.

There are other reasons to believe that this was the case, aside from historical evidence from later periods. In his micro-study of medieval farm management techniques, Stone (2001) emphasizes the role of the information constraints that farm managers faced when making crucial economic decisions. It is in such a context that information-sharing among manorial peers should have been very impactful. What kind of management practices would have been shared across the feudal network? A first and obvious candidate is the diffusion of innovative technologies across Domesday England. Due to their public nature, innovations can be easily diffused through local and social networks.[26] As a result, learning from peers has been identified as a key driver in the adaption of new agricultural technologies.[27] Historical evidence on knowledge spillovers in early 20th-century agriculture similarly highlights the importance of interaction among neighbors and social peers alike (Parman, 2012).

It is now generally taken for granted that technological progress in medieval agriculture was a gradual process with little room for macroinventions. Instead, agricultural progress materialized through “a long chain of small improvements” (Persson, 1988, 28), such as the emergence of mixed-farming systems, crop rotation, and the supportive use of livestock farming.[28] There must have been great variation in the extent that manorial managers were able to adapt and apply these new best-practice techniques successfully. In such a context, the institutionalized interaction between a heterogeneous set of feudal landholders has great potential to materialize spillovers of agricultural knowledge.

Additionally, feudal clustering of higher levels of labor intensity, or even labor exploitation, could occur.[29] Such an interpretation would align closely with Marxist theories of feudalism, in which the exploitation of unfree peasants and the disregard for technological progress are inevitable consequences of the feudal class structure. For example, Brenner (1976) (in)famously states that “the lord’s most obvious mode of increasing output from his lands was not through capital investment and the introduction of new techniques, but through ‘squeezing’ the peasants, through raising either money-rents or labour-services”. In the context of our empirical approach, this implies

[26] A limiting factor to this could be the site-specific nature of certain agricultural technologies and the lack of general-purpose technologies, as highlighted by Mokyr (1990, 32).

[27] See Foster and Rosenzweig (2010) for a discussion on the literature of learning spillovers in agriculture.

[28] To be more precise, Campbell (1997) identifies seven concrete channels through which agricultural change could have been facilitated in the centuries following the Conquest: (1) a renewed focus on more productive agricultural food chains, such as crops instead of animal products; (2) the substitution from less to more productive crops; (3) the emergence of mixed-farming systems; (4) the diversification of rotations; (5) the intensification and rationalization of the labor process; (6) improvements to tools and equipment; (7) increased specialization due to market expansion. This illustrates in which dimensions production processes could have varied across manors.

[29] Note that Domesday Book data does not allow us to differentiate between different levels of production factor intensity. In other words, as only the number of laborers is observed, we do not control for differences in working hours.

that feudal peers share great similarity in the extent to which they "squeeze" their respective manor's inhabitants.

In summary, there are credible reasons to believe that the pervasive nature of feudal society also affected a wide range of microeconomic decisions in the High Middle Ages, ranging from information transmission to agricultural cooperation.[30] In what follows, we trace these mechanisms through the reconstruction of the feudal network of King William I. This will then allow us to unearth feudal interdependencies in Domesday book, both in a reduced-form (Section 5.1) and in a more structural framework (Section 5.2).

Feudal network To study the feudal interdependencies across Domesday manors, we represent the feudal system of William the Conqueror as one comprehensive network, composed of various linked neighborhoods. Manor j is defined to be in the feudal neighborhood $\mathcal{F}_i$ of manor i either when they share the same tenant-in-chief (condition (i)) or lord (condition (ii)), or when the tenant-in-chief of one manor is the lord of the other (condition (iii)). Formally, we can write these three conditions as:[31]

$$j \in \mathcal{F}_i \iff \begin{cases} \text{tenant-in-chief of } i = \text{tenant-in-chief of } j, \ \textit{or} & (i) \\ \text{lord of } i = \text{lord of } j, \ \textit{or} & (ii) \\ \text{tenant-in-chief of } i = \text{lord of } j, \ \textit{or} \text{ tenant-in-chief of } j = \text{lord of } i & (iii). \end{cases}$$

One can represent the entire feudal network compactly in terms of a symmetric feudal network matrix $\mathbf{F}$:

$$\mathbf{F} = [f_{ij}], \qquad f_{ij} = \begin{cases} 1, & \text{if } j \in \mathcal{F}_i, \\ 0, & \text{if } j \notin \mathcal{F}_i. \end{cases}$$

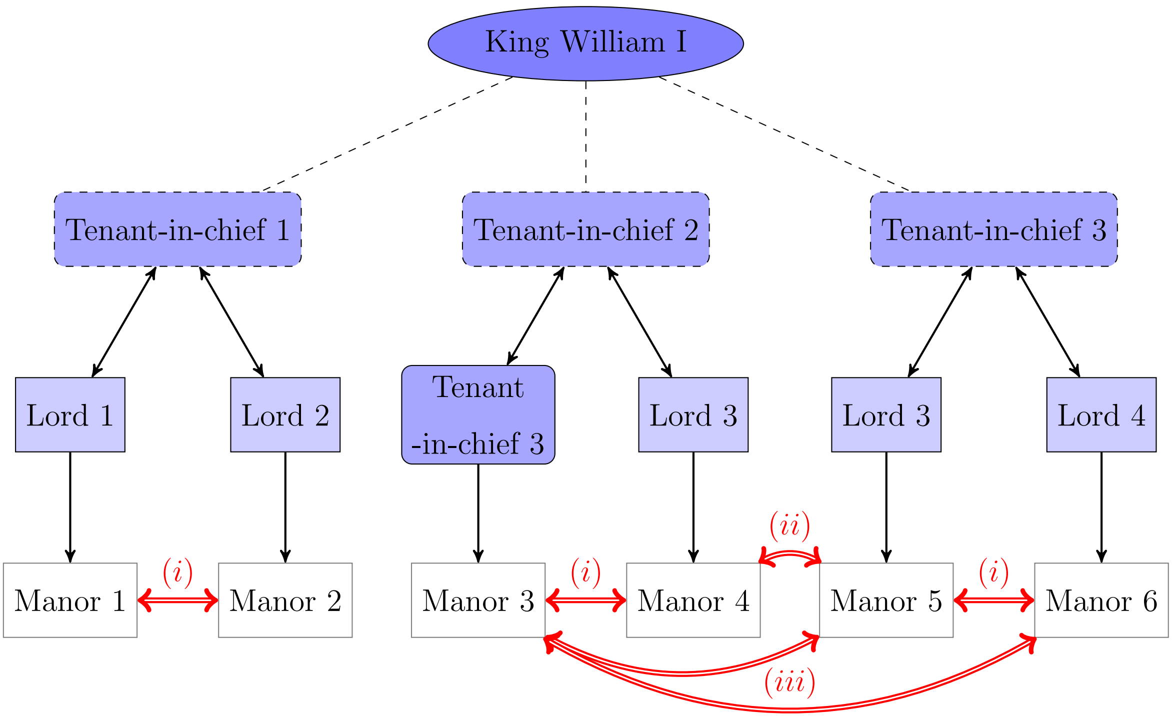
Example We illustrate these concepts with an example of a simplified feudal system, presented in Figure 1, in which three tenants-in-chief own all of King William's lands. The three landowners in turn sublease their lands to two lords. These could also be

[30] An alternative explanation to consider is the formation of the network itself, also known as *network endogeneity* in the literature on social interactions. In our context, it arises if unexplained productivity is correlated with the layout of the feudal system. We return to this issue in depth in Section 6.1.

[31] In accordance with the literature, we also require that a manor is never part of its own neighborhood: i.e. $i \notin \mathcal{F}_i$. In addition, note that our definition yields undirected network links such that $j \in \mathcal{F}_i$ if and only if $i \in \mathcal{F}_j$.

tenant-in-chiefs themselves, as is the case for manor 3. Since this construction was not uncommon in 11^{th}-century England, let us consider the neighborhood of manor 3. In our set-up, manors 3 and 4 are connected to each other because of condition (i), i.e. they share the same tenant-in-chief. As manor 3's lord is also the tenant-in-chief of manors 5 and 6, condition (iii) implies that manor 3 is connected to manors 5 and 6 as well. As a result, elements in the third row (column) of matrix $\mathbf{F}$ will be equal to one in the fourth, fifth, and sixth column (row).

Figure 1: **A simplified example of the Anglo-Norman feudal network**



Note: ⇔ **arrows** represent links (i.e. edges) in the network.

Applying these definitions to the feudal system as recorded in Domesday Book, we (re)construct the feudal network of 11^{th}-century England. In this network, about 68% of the $1,550,125$ links across Anglo-Norman manors are generated by the fact that manors share a tenant-in-chief, i.e. condition (i). Lords were largely dedicated to a specific tenant-in-chief, with only about 2% of the edges rooted in condition (ii). In other words, lords were mostly, but not exclusively, confined to the subtree of their tenant-in-chief. This is intuitive, given that lords were expected to swear an oath of fealty, and to attend his vassal's private courts for advice (Dyer, 2009, 86). Alternatively, tenants-in-chief were connected across subtrees of the network and leased property from other tenants-in-chief in the remaining 30% of the cases.

At the level of the manor, the size of the feudal neighborhood (i.e. degree) shows great variation. On average, a Domesday manor is connected to 136 other manors. Half of the manors, however, have a degree of 59 or less. In other words, the mean degree is skewed by a selection of well-connected manors owned by important landowners. In Appendix A, Tables A2 and A3 present the most influential tenants-in-chief and lords, respectively, in terms of the size of their estate.

Geographic network To fully account for the importance of regional effects, we go beyond the inclusion of county fixed effects and also construct a geographic network. The resulting matrix $\mathbf{G}$ controls for the distance between all manors in Domesday Book. The idea is that neighboring manors were more likely to interact and cooperate, and could more easily observe each others' successful and failing management practices. Such synergies between two farms i and j become less likely when the distance $d_{i,j}$ increases between each other. To capture this, we construct a matrix using double power distance weights,

$$\mathbf{G} = [g_{ij}], \qquad g_{ij} = \begin{cases} (1 - (d_{i,j}/d)^2)^2), & \text{if } j \in \mathcal{G}_i, \\ 0, & \text{if } j \notin \mathcal{G}_i, \end{cases}$$

where the distance parameter d implicitly defines the magnitude of the spatial neighborhood under consideration: i.e. $j \in \mathcal{G}_i \iff d_{i,j} \leqslant d$. If the distance between the two farms is larger than d, the influence becomes zero.

To obtain our main results, we set the distance parameter equal to 20km.[32] The choice of spatial weights is always arbitrary to an extent, thus we mitigate such concerns by a range of robustness checks. These are discussed in Section 6.2. With the construction of matrices $\mathbf{F}$ and $\mathbf{G}$, we now have the tools to comprehensively incorporate the feudal nature of the manorial economy in our analysis.

[32]This distance was chosen so it could be covered in a typical day's journey, as argued in recent historical research (Claridge & Gibbs, 2020, 21).

5 Networks and manorial prosperity

5.1 Reduced-form evidence

Before extending the linear specification of Section 3, we present some correlational evidence that supports the hypothesis that there was a significant degree of economic interaction through the feudal network. We consider two measures of economic productivity: the value-to-labor and value-to-capital ratios.[33] For each measure, we regress the manors' own ratio on the average ratio of the manors in its feudal or spatial neighborhood, controlling for agricultural suitability and county fixed effects. The results are presented in Table 3.

We find that the value-to-resource ratios, which can be loosely interpreted as factor productivity, are highly spatially correlated across medieval England (columns (1) and (2)). Common determinants of agricultural productivity are a likely explanation for such a pattern, as controlling for agricultural suitability and county level effects only absorb part of the spatial correlation. Crucially, we also find highly correlated value-to-resource ratios across the feudal network (columns (3) and (4)). Interactions with feudal peers were only half as important as those with neighbors. If we only consider feudal peers located more than 20km away in the calculation of average peer ratio (columns (5) and (6)), the ratios are still highly correlated and significant, which suggests that the correlations across the feudal network are not merely driven by geographic proximity.

Given the empirical importance of both spatial and feudal connections, an important challenge in identifying the feudal networks' role is to distinguish its effects from the role of the spatial network. If the feudal and spatial network were identical, it would be impossible to differentiate the role of the former from the latter. Fortunately, manors with common ownership were scattered throughout 11^{th}-century England. For instance, Fleming (1991, 180) describes how Norman holdings in Yorkshire did not form "any sort of compact territory". This regional variation can be easily demonstrated by looking at the geographical spread within a single estate. In Figure 2, we present the example of the estate of Robert, Count of Mortain, who was a major

[33]We define value to labor as a manor's value divided by the sum of its non-slave and slave labor, and value to capital as its value divided by the sum of its ploughs and ploughlands.

Table 3: **Correlations across the feudal and spatial network (OLS)**

	Spatial		**Feudal**		**Feudal** ($d > 20$)	
Parameter	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Value-to-labor peers	0.65***		0.34***		0.18***	
	(0.05)		(0.03)		(0.02)	
Value-to-capital peers		0.92***		0.46***		0.38***
		(0.06)		(0.03)		(0.03)
County FE	YES	YES	YES	YES	YES	YES
Soil FE	YES	YES	YES	YES	YES	YES
Observations	9,083	9,083	8,950	8,950	8,731	8,731
R^2	0.29	0.41	0.31	0.42	0.30	0.42

Note: All ratios are in logarithms. The correlations are calculated on the subsample of manors for which the average peer ratio is non-zero. Standard errors are in parentheses.
$*** : p < 0.01, ** : p < 0.05, * : p < 0.1$

landowner in Domesday England.[34] It is clear that his estate was scattered all over the kingdom, a characteristic which was not rare in Anglo-Norman England (for example, see Dyer, 2009, 82). In conclusion, this stylized fact of the feudal network enables us to compare manors with similar location endowments but distinct feudal characteristics (and vice versa), and to examine the impact of the latter on the holding's value.

5.2 Structural evidence

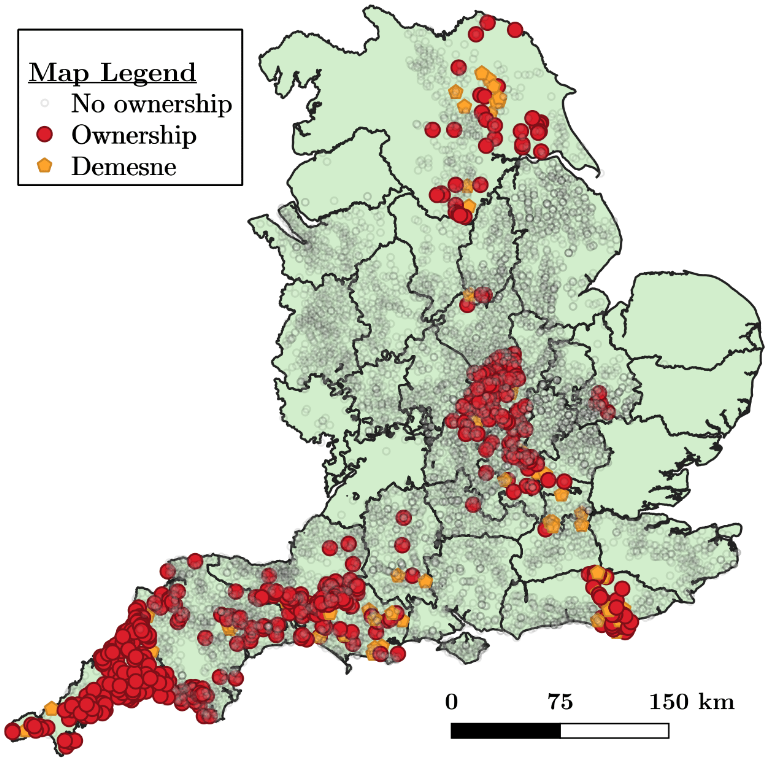
In this section, we introduce a structural interactions model that provides a rich, yet parsimonious, description of the feudal interdependencies between manors, while also controlling for spatial autocorrelation through the geographical network.[35] The model enables us to assess the relative contributions of the feudal and geographical network to Marshall's (1890) external economies of scale. Moreover, it allows us to decompose these economies of scale into a productivity and scale spill-over effect.

Channels In line with the earlier highlighted historical evidence (see Section 3), we hypothesize two channels through which feudal interactions could have taken place,

[34]For more examples, refer to Appendix B. This illustrates that even for smaller landowners, there was considerable variation in the geographical endowments of manorial holdings within- and cross-county.

[35]It is argued by Esteves and Mesevage (2019) that such a structural interactions model is to be preferred above the ad-hoc inclusion of network characteristics in an OLS regression like Equation (1).

Figure 2: **Estate of the Count of Mortain**



Source: Palmer (2010); historical county borders from Brookes (2017)

and modify Equation (1) accordingly. First, we consider the possibility that human capital was shared among feudal peers in the form of productivity spill-overs. In the information-constrained world of Domesday England, public knowledge about agricultural micro-inventions could have easily transferred through institutionalized interactions of related landowners. In a specification such as Equation (1), this implies that the error terms are correlated across the feudal network.

Second, we allow for the possibility of scale-spillovers among connected manors. Such spill-overs arise when the feudal or geographic clustering of large-scale manors, in the form of the high values of y_i, induces a reduction in production costs. For instance, neighboring high-value manors could more easily cooperate to provide public infrastructure, such as bridges, facilitating even higher agricultural production. While we expect such coordination to be more important for the geographic network than for the feudal network, such mechanisms might also arise across feudal peers. This becomes particularly clear in the context of the bridge example, as Cooper (2006, 66) describes how bridgework evolved from a communal obligation under the Anglo-Saxons, to a highly feudal affair under the Normans.

Another way feudal interdependencies could potentially play a role is through the pooling of resources, captured in the vector $\mathbf{x_i}$. However, there are historical reasons to believe that this was implausible. It is unclear how certain manorial values, such as land, would have a direct effect on a feudal peer's agricultural activities. While other resources, such as labor or ploughteams, could plausibly have been shared, we argue that this is unlikely. Such interactions would be highly constrained by the feudal network, as these resources had limited mobility. Moreover, harvest periods were highly time-constrained, meaning resources were indispensable to the manors they belonged to.

Model In our structural network model, we again specify the value y_i of manor i as a linear function of its resources $\mathbf{x}_i$ and an unobserved error term ε_i. In contrast to the reduced-form model in Equation (1), we now allow a manor's value y_i, and its unobserved productivity ε_i, to depend on the values and unobserved productivity of the manors in its feudal neighborhood $\mathcal{F}_i$, and geographic neighborhood $\mathcal{G}_i$.[36] This allows our model to capture and disentangle the two channels of scale spillovers and productivity spillovers.[37]

In particular, we assume that the value y_i of a manor i depends on not only its own resources $\mathbf{x}_i$, but also on the average value of its peers in both neighborhoods, and an unexplained productivity term ε_i,

$$y_i = \alpha + \mathbf{x}_i \boldsymbol{\beta}' + \delta_F \frac{\sum_{f \in \mathcal{F}_i} y_f}{|\mathcal{F}_i|} + \delta_G \frac{\sum_{g \in \mathcal{G}_i} y_g}{|\mathcal{G}_i|} + \varepsilon_i,$$

in which $\boldsymbol{\beta}$ denotes the direct effect of the manor's resources and δ_F (δ_G) captures scale spillovers from feudal (geographic) neighbours. The unexplained productivity term in turn depends on the manor's innate productivity η_i and the average unexplained productivity of its peers in both neighborhoods,

$$\varepsilon_i = \lambda_F \frac{\sum_{f \in \mathcal{F}_i} \varepsilon_f}{|\mathcal{F}_i|} + \lambda_G \frac{\sum_{g \in \mathcal{G}_i} \varepsilon_g}{|\mathcal{G}_i|} + \eta_i, \quad \mathbb{E}[\eta_i \mid \mathbf{X}, \mathbf{F}, \mathbf{G}] = 0,$$

[36] In Appendix C, we present results for a model that includes only productivity spillovers.

[37] Informally, we can separately identify both mechanisms from the data because the networks have a sparse structure. That is, there are pairs of manors in data between which the shortest network path is sufficiently long.

where λ_F (λ_G) captures spillovers in productivity from feudal (geographic) neighbors.[38] Stacking observations, this model can be rewritten compactly in matrix notation:

$$\mathbf{y} = \alpha\boldsymbol{\iota} + \mathbf{X}\boldsymbol{\beta}' + (\delta_F\mathbf{F} + \delta_G\mathbf{G})\mathbf{y} + \boldsymbol{\varepsilon}, \quad \boldsymbol{\varepsilon} = (\lambda_F\mathbf{F} + \lambda_G\mathbf{G})\boldsymbol{\varepsilon} + \boldsymbol{\eta}, \quad \mathbb{E}[\boldsymbol{\eta} \mid \mathbf{X}, \mathbf{F}, \mathbf{G}] = 0. \tag{2}$$

In this expression, $\mathbf{F}$ and $\mathbf{G}$ are adjacency matrices as defined in previous section.[39] This model can be estimated consistently and efficiently by using the generalized spatial two-stage least squares (GS2SLS) procedure proposed in Kelejian and Prucha (2010) and Drukker, Egger, and Prucha (2019).

The interpretation of the coefficients in our model is less straightforward than those in an OLS regression. In general, the parameters can not be understood as marginal effects, as the latter also depend on the underlying network structure. Consider, for example, the simple network with three nodes that is depicted in Figure 3. If an exogenous shock shifts manor i's innate productivity η_i with Δ, its productivity ε_i initially (in step s_1) also rises by this amount. In the next step, due to the feudal structure, its direct feudal peer j will experience an effect on its productivity ε_j, but now of size $\lambda\Delta$. The same mechanism again induces a productivity spillover of size $\lambda^2\Delta$ to manors i and k in step s_3. This mechanism goes on forever, but the additional terms become negligibly small as the number of steps increases. We also note that the further away a manor is removed in the feudal network, the smaller the effect becomes. A similar mechanism is at work when a shock in x_i or ε_i (the latter caused by a shock in $\boldsymbol{\eta}$) changes the value of y_i.

[38] A sufficient condition for this model to have a stable and unique solution is that $|\lambda_F| + |\lambda_G| < 1$ and $|\delta_F| + |\delta_G| < 1$.

[39] In accordance with the literature, we normalize $\mathbf{F}$ and $\mathbf{G}$ such that all rows sum to unity, except for the rows belonging to isolated manors. A manor is called isolated when it has no links with other manors in the network. In other words, its neighborhood is empty.

Figure 3: **An illustration of productivity spill-over in the baseline model**

$$
\begin{array}{llccccc}
\text{shift in } \eta & & \Delta & & & & \\
 & & \downarrow & & & & \\
 & & \text{manor } i & \text{———} & \text{manor } j & \text{———} & \text{manor } k \\
 & & \downarrow & & \downarrow & & \downarrow \\
\text{shift in } \varepsilon & \text{step } s_1 & \Delta & & 0 & & 0 \\
 & \text{step } s_2 & 0 & & \lambda\Delta & & 0 \\
 & \text{step } s_3 & \lambda^2\Delta & & 0 & & \lambda^2\Delta \\
+ & & \vdots & & \vdots & & \vdots \\
\hline
 & & (1+0+\lambda^2+\ldots)\Delta & & (0+\lambda+0+\ldots)\Delta & & (0+0+\lambda^2+\ldots)\Delta
\end{array}
$$

To overcome this difficulty, we report the more easy to interpret summary measures, as suggested by LeSage and Pace (2009, 39). These measures divide the average total effect (ATE) into an average direct effect (ADE) and an average indirect effect. In our context, the ADE is defined as the expected impact on a given manor i's value when its innate productivity η_i is increased by 1. Therefore, it can be interpreted as an average marginal effect of a shock in the latter variable. Alternatively, the ATE is defined as the expected impact on a given manor i's value when the innate ability of *all* manors is increased by 1. The average indirect effect is then defined as the difference between the average total and indirect effect. To facilitate interpretation, the ADE and ATE for every mechanism are reported separately, so that their relative magnitude can be assessed. These statistics are calculated by putting the coefficient(s) of the other mechanism at 0, which effectively shuts down that channel.

Results Table 4 presents the estimates for our structural network model. Overall, we find large positive and statistically significant effects for the productivity spill-over parameters in all specifications considered. When only one of both networks is included (columns (1) and (2)), we have that $\widehat{\lambda}_F$ equals 0.79 and $\widehat{\lambda}_G$ equals 0.92. In these cases, the feudal and geographic networks capture part of each other's effect due to their, previously highlighted, correlated nature. As a consequence, modelling both networks simultaneously (column (3)) reduces both estimates to 0.38 for $\widehat{\lambda}_F$ and 0.65 for $\widehat{\lambda}_G$. The inclusion of county and soil quality fixed effects (columns (4), (5), and (6)) absorbs some of, but not all of the network effect. The scale spill-overs through the geographic network are quite substantial, with estimates for δ_G ranging from 0.17 (column (2)) to as high as 0.44 (column (3)). However, these scale effects are dominated consistently by

Table 4: **Estimates of the structural model (GS2SLS)**

Parameter			**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
Labor: non-slaves		β_1	0.19***	0.15***	0.15***	0.17***	0.15***	0.15***	0.15***
			(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Labor: slaves		β_2	0.12***	0.09***	0.09***	0.11***	0.09***	0.10***	0.10***
			(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Capital: ploughs		β_3	0.55***	0.60***	0.58***	0.56***	0.59***	0.57***	0.57***
			(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Land: ploughlands		β_4	0.13***	0.14***	0.14***	0.13***	0.14***	0.14***	0.14***
			(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Constant		α	-0.35***	-0.47***	-0.91***	-0.29***	-0.49***	-0.63***	-0.63***
			(0.03)	(0.05)	(0.04)	(0.03)	(0.05)	(0.06)	(0.06)
Productivity spill-overs	$\mathbf{F}$	λ_F	0.79***		0.38***	0.45***		0.36***	0.22***
			(0.02)		(0.04)	(0.03)		(0.03)	(0.03)
	$\mathbf{G}$	λ_G		0.92***	0.65***		0.62***	0.51***	0.38***
				(0.03)	(0.02)		(0.03)	(0.03)	(0.03)
	$\mathbf{F}\cdot\mathbf{G}$	$\delta_{F\cdot G}$							0.18***
									(0.02)
Scale spill-overs	$\mathbf{F}$	δ_F	0.08***		0.10***	0.09***		0.10***	0.10***
			(0.02)		(0.01)	(0.01)		(0.01)	(0.01)
	$\mathbf{G}$	δ_G		0.17***	0.44***		0.21***	0.25***	0.24***
				(0.03)	(0.02)		(0.03)	(0.03)	(0.03)
	$\mathbf{F}\cdot\mathbf{G}$	$\delta_{F\cdot G}$							0.00
									(0.01)
County FE						YES	YES	YES	YES
Soil FE						YES	YES	YES	YES
Observations			9,084	9,084	9,084	9,084	9,084	9,084	9,084
ADE productivity spill-overs			1.07	1.04	1.03	1.01	1.01	1.03	1.02
ADE scale spill-overs			1.00	1.00	1.01	1.00	1.00	1.00	1.00
ADE combined			1.08	1.05	1.06	1.02	1.02	1.04	1.03
ATE productivity spill-overs			3.83	5.56	7.51	1.81	2.53	6.92	3.63
ATE scale spill-overs			1.08	1.21	2.11	1.09	1.27	1.32	1.51
ATE combined			4.16	6.74	15.88	1.98	3.22	9.13	5.50

Note: Standard errors are in parentheses.
$*** : p < 0.01, ** : p < 0.05, * : p < 0.1$

the dependence in the unobserved productivity term, as both the ATE and the ADE are larger for the productivity spill-overs. As we highlighted earlier in this section, there is more potential for scale spill-overs through the geographic network than the feudal network. The estimates for the resources $\boldsymbol{\beta}$ are comparable to those of the preferred specification (column (4) in Table 2) in the the reduced-form model.

Additionally, in column (7) we present estimates for a model that contains an interaction effect between the feudal and the geographic network. Such an interaction effect allows for a differential impact of feudal peers, depending on their geographic distance to a manor, as it might be reasonable to presume that peers who are neighbors in both networks exhibit stronger effects.[40] We find a positive and significant interaction effect for the productivity spill-overs mechanism. However, the effect for scale spillovers is both economically and statistically insignificant.

Our model also allows to test whether the effects through the feudal network are heterogeneous across different types of manors. Did a manor's amount of feudal peers contribute to the feudal spillover mechanism? And were religious or secular holdings more keen on interacting with its network neighbors? To answer these questions, we estimate a model as in column (6), but with the inclusion of an interaction of the relevant source of heterogeneity with peers' average unobserved productivity (for the productivity spillovers) and average value (for the scale spillovers). We find that both effects significantly increase with the size of the feudal neighborhood, although the rise in spillover effects in productivity is the most marked (Figure 4a). This heterogeneity is not unsurprisingly, given that such manors might had have a higher probability of interacting with the most innovative manors. In addition, we find that manors with religious ownership also experience much higher spillover effects than those with secular ownership (Figure 4b). This can be attributed to two factors. First, the organizational hierarchy of ecclesiastical domains facilitated closer interactions between its manors, encouraging extensive communication among its laborers and managers.[41] Second, these extraordinary spillover effects can be interpreted within the long-established idea that ecclesiastical domains were forerunners in the adoption of medieval agricultural innovations.[42]

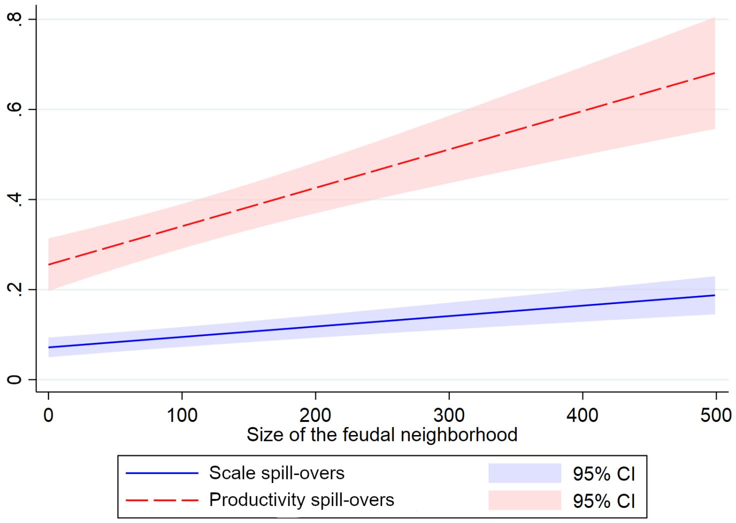
Finally, we investigate whether the observed feudal effects are driven by interac-

[40]We construct the adjacency matrix of the interaction terms, say $\mathbf{F} \cdot \mathbf{G}$, by weighting the feudal connections with spatial weights. Formally, we define $\mathbf{F} \cdot \mathbf{G}$ as the row-normalised Hadamard product between $\mathbf{F}$ and $\mathbf{G}$: i.e. $[\mathbf{F} \cdot \mathbf{G}]_{ij} = f_{ij}g_{ij} / \sum_j f_{ij}g_{ij}$.

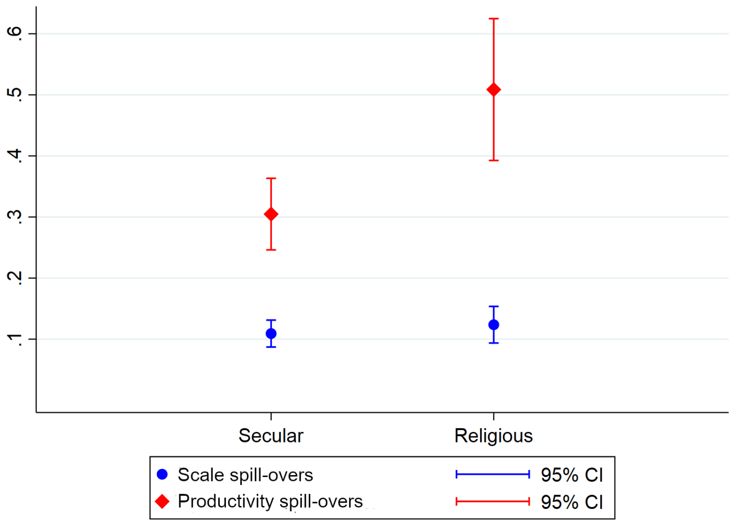
[41]The emergence of the obedientiary system implied increasing specialization among the members of religious organizations. For instance, Farmer (1991, 378) documents how 13^{th}-century monastic estates dispatched their obedientiaries to oversee the reeves of their respective manors in their market purchase decisions. For a discussion of the changing organizational structures of monastic houses and the effects on management and information flows within church estates, see Dobie (2008). In this context, it could also be that incentives for clerical reeves were more trained towards group objectives, whereas secular reeves were more interested in gaining comparative advantages over their peers. Furthermore, recent empirical research has highlighted the economic benefits of the democratic nature of religious organizations of that time (Rossignoli & Trombetta, 2021). Democratic rule could potentially have contributed to inter-manorial cooperation as well.

[42]This notion is established in several traditional works on medieval history. Pirenne (1969, 11) saw the clergy's superior levels of education as the root of the Church's economic ascendancy ("*l'ascendant économique*"). Boissonnade (2005, 157) described church domains as "centres in which agricultural science was developed, forestry and scientific breeding improved, model farms created, new crops tried, and agricultural production regenerated and stimulated".

Figure 4: **Heterogeneous feudal network effects**



(a) Size of the feudal neighborhood



(b) Secular versus religious ownership

tions among manors within the same estate, i.e. manors possessed by the same lord, or also by spillovers between estates. Certain spill-over mechanisms, primarily the possibility of having common ownership structures, can be expected to play a larger role within a single estate. To formalize this, we separate the feudal network into two distinct networks, F_W and F_B. The former captures connections between manors belonging to the same estate (i.e. network condition (*ii*)), while the latter captures connections through a common tenant-in-chief or in situations where the tenant-in-chief, of one manor is the lord of the other (i.e. network conditions (*i*) and (*iii*)), respectively). In an elaborated model, we allow for spillovers through both networks separately. Crucially, the results in Table A5 in the Appendix highlight that feudal correlations are not solely driven by economic interactions within a single estate. More specifically, we observe that scale and productivity spill-overs play a statistically significant and sizable role through manorial interactions both within and across estates. As a result, the observed interaction effects are not merely the result of common management structures across manors of the same owner.

6 Sensitivity analysis

6.1 Network endogeneity

Collusion of powerful nobles striving to obtain the most productive landholdings could explain the feudal clustering of economic activity. This is especially important in the context of King William's England, as the feudal system under investigation was only put in place twenty years earlier. Such endogeneity concerns are fundamentally inherent to any non-experimental empirical work on interaction effects, but are mitigated by the historical origins of the Anglo-Norman feudal institutions. A first argument is that the structure of the feudal system was strongly influenced by non-economic features, like military and political considerations. In his 'tenurial revolution', William the Conqueror structurally reshaped the landscape of England to his own view. Landholdings with great defensive importance close to the borders or the sea were especially sought after by the landed elite (Fleming, 1991, 147). A second argument is that the formation of the feudal system, if actually influenced by economic considerations, was likely to be based on easily observable proxies for the value of manors. Although our structural model will not allow for network formation based on unexplained productivity, it does allow for network formation on the resources. That is, even if the newly created feudal system was mainly based on population density and the availability of lands and ploughs, our estimates are still consistent and can be interpreted as actual spill-over effects.[43] Third, we refer to our previous observation of network interactions being significantly larger for ecclesiastical domains in comparison to seignorial manors. Given that the Conquest left the continuity of several church holdings largely unaffected (Dyer, 2009, 83-84), this provides further evidence that network endogeneity was not a likely explanation for the observed network effects.

Aside from this historical evidence, we propose two empirical tests to examine the issue of network endogeneity. First, one can leverage the 1066 values in Domesday Book to examine the relationship between a manor's economic changes over the two decades following the Conquest and its network properties in 1086.[44] If network endogeneity was the sole driving factor of the observed peer effect, one would expect the powerful elite to obtain lands with high valuation in 1066, and to observe no relationship between ownership characteristics and growth in agricultural performance over the following decades. In contrast, if the aforementioned interaction mechanisms were in play, being part of a productive ownership cluster would induce economic development. To test the presence of such a network *treatment effect*, we regress the difference in log values between 1066 and 1086 on the average value-to-labor and value-to-capital of peers. The results of this exercise can be found in Table 5. We find that the values of those within better feudal networks (i.e. more efficient peers in 1086) have enjoyed substantially more value growth. This is a strong indication that having productive feudal peers indeed leads to manors thriving in terms of economic prosperity.

[43] In contrast, if the construction of the feudal network was influenced by unobserved productivity, our spill-over estimates might be inflated.

[44] It is worthwhile to mention that the 1066 data should be regarded with great scrutiny. Domesday Book technically reports the feudal network, as well as the manors' valuation, both before and after the Conquest (in 1066 and 1086 respectively). Inconsistent reporting makes these variables problematic to analyze, however. The root for this is likely to be found in its anecdotal nature: the 1066 data in Domesday Book was collected by questioning landowners on the state of their lands in the time of King Edward. We reckon that this raises several concerns regarding the reliability of this data (most notably, the lack of verifiability by the commissioners), and we hence chose to omit this this data from the main analysis. In many seminal works of Domesday scholarship, however, the changes in values and ownership over the 1066-1086 period are generally regarded to be representative of changes in economic prosperity, war damages and inheritance practices (for example, see Fleming, 1991, 123 and references therein).

Table 5: **Change in values (1066–1086) and peer productivity (OLS)**

Parameter	**(1)**	**(2)**	**(3)**	**(4)**
Value-to-labor peers	0.78***		0.60***	
	(0.07)		(0.08)	
Value-to-capital peers		0.53***		0.28***
		(0.05)		(0.06)
Value 1066	-0.41***	-0.41***	-0.40***	-0.40***
	(0.00)	(0.00)	(0.01)	(0.01)
Constant	0.65***	0.66***	0.52***	0.58***
	(0.02)	(0.02)	(0.03)	(0.03)
County FE	NO	NO	YES	YES
Soil FE	NO	NO	YES	YES
Observations	5,926	5,926	5,926	5,926
R^2	0.42	0.42	0.66	0.66

Note: Standard errors are in parentheses.
$*** : p < 0.01, ** : p < 0.05, * : p < 0.1$

Second, we conduct a graphical test for network endogeneity which is based on the discussion in Boucher and Fortin (2016). In this test, that is detailed in Appendix E, a model of network formation is assumed that exhibits homophily.[45] Given our structural model, when network formation is endogenous, the presence of homophily induces some testable implications on the joint distribution of the residuals of both models. The bivariate kernel density plots suggest that endogeneity, if present, is likely not a substantial issue.

6.2 The obscurities in Domesday Book

Domesday Book presents a unique quantitative insight into an 11$^{\text{th}}$-century economy. Nevertheless, it remains a complex historical document, created in a time when centrally organized inquiries of the like were unknown. The resulting obscurities, both in structure and content, have been identified as a prime cause for the surprising neglect of Domesday Book by economists (for an up-to-date discussion on the matter, see Walker, 2015). In what follows, we scrutinize how the unresolved uncertainties in

[45]Homophily arises when manors with similar characteristics are more likely to form feudal links.

Domesday Book are to be interpreted within the context of our findings.[46]

Network mismeasurement While we argue that the network presented in this paper, is the closest anyone will ever come to comprehensively measuring a feudal network, it is still crucial to assess whether our results are sensitive to the incomplete identification of Anglo-Norman landowners. The mismeasurement of networks is an ever-present concern in empirical work on peer effects. This is especially relevant in the construction of network matrices of an historical nature.

About 85% of landowners in Domesday Book are identified with reasonable certainty. It is likely that the remaining manors with unidentified ownership structure are somewhat different in an unobserved nature. The mismeasurement of these intermanorial connections could, therefore, induce selection bias in our network estimates. As discussed before in Section 2, we consider manors with missing identification on their lordship as having their own idiosyncratic lord. These manors are connected to the network only through their identified tenant-in-chief. To assess the impact of this assumption, we reestimate our interactions models on the extreme premise that among the unidentified lords, those with the same name within a given circuit are in fact identical individuals. Table A6 in the Appendix shows that this leaves our results basically unaltered. Moreover, we conduct an additional sensitivity check in which all manors with unidentified ownership were dropped from the sample. This sensitivity check also has very little impact on our results (see Table A7); we may conclude that our estimates are most likely not driven by network mismeasurement.

The geography of Domesday Book Our analysis paid close attention to the disentanglement of the feudal and geographic network effects. To achieve this, we relied on the geographic picture of England that is presented by Domesday Book. In the introduction to his seminal study, Darby (1977, 13) claims that this picture "while neither complete nor accurate in all its details, does reflect the main features of the geography of the eleventh century". The question we ask here is whether these omissions and inaccuracies drive our results in any way.

[46]The early seminal work of McDonald and Snooks (1986), who were the first to apply econometric analysis to Domesday Book, was built on the premise that Domesday Book was "not a particularly complex document" (McDonald & Snooks, 1987, 252). This stance is, however, difficult to defend given the the large strand of Domesday literature on the peculiarities of the historical source at hand.

One such uncertainty lies in the nature of the manorial concept in Domesday Book. In the majority of cases, these holdings were confined to a single location, making up a small community or being part of a larger village. However, Domesday manors were sometimes scattered across several locations. Until now, these manors were omitted from the analysis, as the disentanglement of feudal and regional peer effects can only be made with less certainty. We can not rule out that this induces a selection effect as multiple-location manors of the like are typically larger, and could differ in their unobservable characteristics. To alleviate such concerns, we devise an alternative strategy, in which we assign these manors to the centroid of their respective locations. To avoid assigning senseless locations to manors, we still drop manors of which one of the locations is further than five kilometres from its centroid. Table A8 reveals that the inclusion of these manors have little impact on the estimated parameters of our models.

Another aspect of Domesday geography which deserves special attention is the role of distance. In our baseline analysis, we modelled the interaction with neighboring manors as a function of distance: the further away one's neighbor, the less strongly that interactions and the subsequent spillover effects occur. The choice of this distance function is contingent on our assumptions with respect to the role of distances, travel, and information in medieval England (for a discussion, see Langdon & Claridge, 2011). Here, we ascertain that these do not drive our results. In our baseline analysis, we used a double power distance function with a parameter d equal to 20km. In Table A9, we evaluate the sensitivity of our models to the choice of d. In particular, we estimate three additional cases, including a low level of $d = 10$km and an implausibly high level of $d = 100$km. The remarkably consistent estimates of the feudal effects $\widehat{\lambda}_F$ and $\widehat{\delta}_F$ across all four cases reveal that the choice of the distance function parameter d does not alter our findings, neither in a qualitative nor a quantitative sense. In addition, Table A10 presents estimates where our weighting function is replaced by binary indicators that indicate whether manors are within (band (i)) 0 to 20km; (band (ii)) 20 to 50km; or (band (iii)) 50-100km of each other. From this table, one can see that the effects for the feudal effect are essentially unaltered. More interestingly, the estimates for the geographic effects are small and mostly statistically insignificant for bands (ii) and (iii). This suggests that geographic effects generally did not reach beyond 20km, or one day's travel, which further supports the use of $d = 20$km in our main specification.

The meaning of Domesday variables While the variables in Domesday Book often show great simplicity at first glance, their interpretation is not always as straightforward. The controversial ploughlands variable, which we introduced in Section 2.2, is the prime example of this. Despite being typically associated with the statement "land for so many ploughs", it is uncertain whether this variable effectively measures the amount of arable land available for the manor's agricultural activities. In our baseline analysis, we took this variable at face value and considered it as a control for the amount of land. In Table A11, we repeat our analysis with the ploughlands variable omitted. In other words, we assume perfect complementarity between land, capital, and labor. In doing so, we extend the sample with manors for which no ploughlands are recorded. It is apparent that our findings with respect to the feudal peer effect are robust to the exclusion of the ploughlands variable and to the inclusion of these manors. The estimated coefficients of interest $\widehat{\lambda}_F$ and $\widehat{\lambda}_G$ are remarkably unchanged. Somewhat unsurprisingly, we observe the biggest impact on the ploughs effect.

Another important discussion is the open debate on Domesday Book's manorial valuations. Many historians have interpreted these *valets* (values) as a measure of income, which the landowner derived from his or her manor. Evidence in support of this theory originates in Galbraith (1929), who illustrated how a Domesday manor was rented out at the price of its value. Additionally, the well-researched case of Canterbury presents great consistency in how the ecclesiastical grounds were valued across 12^{th}-century sources (Du Boulay, 1966). Or, as Dyer (1995, 198) concludes "it is on the basis of such evidence that a case can be made for some comparability between Domesday values and annual income deriving from manors in the twelfth and thirteenth century."

However, it is an open debate as to whether the *valets* comprise the entire stream of revenue which flows to the manorial lord. Some historians argue that only money rents are accounted for, challenging the generally held view that "Domesday values are a more or less accurate index of the productive capacity of estates" (Roffe, 2007, 241). This supposes that these values are a measure of the peasants' cash contributions to the lords, rather than of the manor's own agricultural activities.

Such an interpretation would align poorly with another, more quantitative approach to the nature of Domesday values furthered by McDonald and Snooks (1985). The crux of their argument lies in the close statistical relationship between a manor's resources and valuation, leaving little room for contributions from the peasant side of the economy.[47] Additionally, a more recent study finds a much weaker correlation between peasant ploughteams and valuations, than between the lord's ploughs and the latter (Walker, 2015). This does not lend credence to the interpretation of values as a cash contribution by the manor's peasants. Our results on the feudal structure of valuations in Domesday Book add new evidence to this ongoing debate. That is, it is unclear as to why and how agricultural activities of the peasant economy should be inter-connected across the feudal system, compared to the management practices of the lords in their seigniorial holdings.

7 Final thoughts

This paper presents first evidence on the pervasive nature of feudal institutions in the manorial economy. Building on the land ownership data in Domesday Book, we reinterpret and model the feudal system as a network that facilitates economic interactions. Indeed, we find that landowners' wealth accumulation was closely intertwined with the fortune of their peers. Manorial values in Domesday England were positively, and significantly, influenced by both the unobserved value productivity and the absolute value levels of their feudal peers. The former can be explained by inter-manorial knowledge-sharing mechanisms, which were capable of playing a crucial role in a world where agricultural information was scarce. The latter effect is credited to scale spillovers, facilitated by agricultural cooperation across feudal peers. In this process, we empirically establish the presence of economic interactions between manors during the High Middle Ages, which constitutes first evidence on the role of manorialism in economic integration in that era.

[47]Another explanation would be a high correlation between the manor's and peasants' agricultural performance. However, this renders the discussion on values irrelevant in the context of our paper (unlike, for example, in the context of the reconstruction of the GDP of the Domesday economy). We are only interested in cross-variation in wealth production and, in this case, the *valets* represent this adequately.

Our paper opens up avenues for future research. To start with, our approach to network formation was heavily inspired by the feudal structure as presented by Domesday Book, allowing us to model the 11^{th}-century web of ownership structures in a comprehensive manner. Domesday Book is, however, silent on any other network structures that might affect the economic interaction mechanisms described in this paper. For instance, 11^{th}-century England was a highly multilingual society, compromising of many different cultures and languages. It cannot be ruled out that the intensity of interactions across the feudal network was heavily regulated by this polyglot reality. In a similar manner, family relationships, while largely unknown to the historian, could prove relevant. We did not account for such cultural or familial networks, except for the degree to which these relationships are correlated with the feudal structure. More research on the etymological nature of the names in Domesday Book might offer additional insights into the extent to which this was the case.

Further analysis on the underlying economic and social mechanisms is also required. As with all cross-sectional studies on observational data, it is inherently difficult to isolate the true underlying mechanisms without the help of theoretical arguments and sound judgement. This is especially true for Domesday Book, where only limited and imperfect data is available to researchers. Be that as it may, this unique historical source reveals a fascinating insight into the feudal interdependencies within medieval economies.

References

Acemoglu, D., & Robinson, J. A. (2012). *Why nations fail: The origins of power, prosperity, and poverty.* London: Profile Books.

Andersen, T. B., Jensen, P. S., & Skovsgaard, C. V. (2016). The heavy plow and the agricultural revolution in Medieval Europe. *Journal of Development Economics*, *118*, 133–149.

Biddick, K. (1989). *The other economy: Pastoral husbandry on a medieval estate.* Berkeley: University of California Press.

Biddick, K., & Bijleveld, C. C. (1991). Agrarian productivity on the estates of the Bishopric of Winchester in the early thirteenth century: A managerial perspective. In B. M. Campbell & M. Overton (Eds.), *Land, labour and livestock: Historical studies in european agricultural productivity* (pp. 95–123). Manchester: Manchester University Press.

Bloch, M. (1968). *Feudal society.* Chicago: Chicago University Press.

Boissonnade. (2005). *Life & work in medieval Europe.* New York: Routledge. (Originally published in 1927)

Boucher, V., & Fortin, B. (2016). Some challenges in the empirics of the effects of networks. In Y. Bramoullé, A. Galeotti, & B. Rogers (Eds.), *The Oxford handbook of the economics of networks* (p. 277-302). Oxford: Oxford University Press.

Brenner, R. (1976). Agrarian class structure and economic development in pre-industrial Europe. *Past & Present*, *70*(1), 30–75.

Britnell, R. H. (1993). *The commercialisation of English society 1000-1500.* Cambridge: Cambridge University Press.

Brookes, S. (2017). *Domesday shires and hundreds of England: Metadata* (Tech. Rep.). London: UCL Institute of Archaeology.

Campbell, B. M. (1997). Economic rent and the intensification of English agriculture, 1086-1350. In G. G. Astill & J. Langdon (Eds.), *Medieval farming and technology: The impact of agricultural change in Northwest Europe* (pp. 225–249). Leiden: Brill.

Campbell, B. M. (2006). *English seigniorial agriculture, 1250-1450.* Cambridge: Cambridge University Press.

Claridge, J., & Gibbs, S. (2020). *Waifs and strays: Property rights in late medieval England* (Tech. Rep.). LSE Department of Economic History. (Mimeo)

Clark, G. (2015). Markets before economic growth: The grain market of medieval England. *Cliometrica*, *9*(3), 265–287.

Cooper, A. (2006). *Bridges, law and power in medieval England, 700–1400.* Woodbridge: The Boydell Press.

Darby, H. C. (1977). *Domesday England.* Cambridge: Cambridge University Press.

Dobie, A. (2008). The development of financial management and control in monastic houses and estates in England c. 1200–1540. *Accounting, Business & Financial History*, *18*(2), 141–159.

Drukker, D. M., Egger, P. H., & Prucha, I. R. (2019). *Simultaneous equations models with higher-order spatial or social network interactions* (Tech. Rep.). College Park: University of Maryland.

Du Boulay, F. R. H. (1966). *The lordship of Canterbury: An essay on medieval society.* London: Nelson.

Dyer, C. (1995). Appendix 3: A note on calculation of GDP for 1086 and c. 1300. In R. H. Britnell & B. M. Campbell (Eds.), *A commercialising economy: England 1086 to c. 1300* (pp. 196–198). Manchester: Manchester University Press.

Dyer, C. (2009). *Making a living in the Middle Ages: The people of Britain 850-1520.* New Haven: Yale University Press.

Epstein, S. R. (1998). Craft guilds, apprenticeship, and technological change in preindustrial Europe. *The Journal of Economic History*, *58*(3), 684–713.

Esteves, R., & Mesevage, G. G. (2019). Social networks in economic history: Opportunities and challenges. *Explorations in Economic History*, *74*, 101299.

Farmer, D. L. (1991). Marketing the produce of the countryside, 1200-1500. In J. Thirsk (Ed.), *The agrarian history of England and Wales* (Vols. 3, 1348–1500, p. 324-430). Cambridge: Cambridge University Press.

Fischer, G., Nachtergaele, F. O., Prieler, S., Teixeira, E., Tóth, G., Van Velthuizen, H., ... Wiberg, D. (2012). *Global agro-ecological zones (GAEZ v3.0): Model documentation* (Tech. Rep.). Laxenburg and Rome: IIASA and FAO.

Fleming, R. (1991). *Kings and lords in Conquest England.* Cambridge: Cambridge University Press.

Foster, A. D., & Rosenzweig, M. R. (2010). Microeconomics of technology adoption. *Annual Review of Economics*, *2*(1), 395–424.

Galbraith, V. (1929). An episcopal land-grant of 1085. *The English Historical Review*, *44*(175), 353–372.

Harvey, S. (2014). *Domesday: Book of judgement.* Oxford: Oxford University Press.

Hatcher, J., & Bailey, M. (2001). *Modelling the Middle Ages: The history and theory of England's economic development.* Oxford: Oxford University Press.

Humphries, J., & Weisdorf, J. (2019). Unreal wages? Real income and economic growth in England, 1260–1850. *The Economic Journal*, *129*(623), 2867–2887.

Karakacili, E. (2004). English agrarian labor productivity rates before the Black Death: A case study. *The Journal of Economic History*, *64*(1), 24–60.

Keats-Rohan, K. S. B. (1999). *Domesday people: A prosopography of persons occurring* *in English documents 1066-1166: I. Domesday Book*. Woodbridge: The Boydell Press.

Kelejian, H. H., & Prucha, I. R. (2010). Specification and estimation of spatial autoregressive models with autoregressive and heteroskedastic disturbances. *Journal of Econometrics*, *157*(1), 53–67.

Langdon, J., & Claridge, J. (2011). Transport in medieval England. *History Compass*, *9*(11), 864–875.

Leighton, A. C. (1972). *Transport and communication in early medieval Europe AD 500-1100*. Newton Abbot: David and Charles.

LeSage, J., & Pace, R. K. (2009). *Introduction to spatial econometrics*. Boca Raton: Chapman & Hall / CRC.

Lowerre, A. G. (2016). Geospatial technologies and the geography of Domesday England in the twenty-first century. In D. Roffe & K. Keats-Rohan (Eds.), *Domesday now: New approaches to the inquest and the book* (pp. 219–246). Woodbridge: The Boydell Press.

Marshall, A. (1890). *The principles of economics*. London: MacMillan and Co.

Masschaele, J. (1993). Transport costs in medieval England. *The Economic History Review*, *46*(2), 266–279.

McDonald, J. (1998). *Production efficiency in Domesday England, 1086*. London: Routledge.

McDonald, J. (2015). Entrepreneurship in Wiltshire, England, almost 1,000 years ago. *Cliometrica*, *9*(2), 193–207.

McDonald, J., & Snooks, G. D. (1985). The determinants of manorial income in Domesday England: Evidence from Essex. *The Journal of Economic History*, *45*(3), 541–556.

McDonald, J., & Snooks, G. D. (1986). *Domesday economy: A new approach to Anglo-Norman history*. Oxford: Oxford University Press.

McDonald, J., & Snooks, G. D. (1987). The suitability of Domesday Book for cliometric analysis. *The Economic History Review*, *40*(2), 252–261.

Mokyr, J. (1990). *The lever of riches: Technological creativity and economic progress*. Oxford: Oxford University Press.

North, D. C., & Thomas, R. P. (1973). *The rise of the western world: A new economic history*. Cambridge: Cambridge University Press.

Ogilvie, S. (2004). Guilds, efficiency, and social capital: Evidence from German proto-industry. *The Economic History Review*, *57*(2), 286–333.

Ogilvie, S. (2019). *The European guilds: An economic analysis*. Princeton: Princeton University Press.

Palmer, J. (2010). *Electronic edition of Domesday book: Translation, databases and* *scholarly commentary, 1086; second edition.* UK Data Service.

Parman, J. (2012). Good schools make good neighbors: Human capital spillovers in early 20th century agriculture. *Explorations in Economic History*, *49*(3), 316–334.

Persson, K. G. (1988). *Pre-industrial economic growth: Social organization, and technological progress in Europe.* Oxford: Blackwell.

Pirenne, H. (1969). *Histoire économique et sociale du Moyen Age.* Paris: Presses Universitaires de France. (Originally published in 1933)

Roffe, D. (2007). *Decoding Domesday.* Woodbridge: The Boydell Press.

Rossignoli, D., & Trombetta, F. (2021). *Ora et guberna. The economic impact of the rule of St Benedict in medieval England* (Tech. Rep.). Università Cattolica del Sacro Cuore. (mimeo)

Round, J. H. (1895). *Feudal England: Historical studies on the XIth and XIIth centuries.* Cambridge: Cambridge University Press.

Schneider, E. B. (2014). Prices and production: Agricultural supply response in fourteenth-century England. *The Economic History Review*, *67*(1), 66–91.

Slavin, P. (2012). *Bread and ale for the brethren: The provisioning of Norwich cathedral priory, 1260-1536* (Vol. 11). University of Hertfordshire Press.

Stone, D. (2001). Medieval farm management and technological mentalities: Hinderclay before the Black Death. *The Economic History Review*, *54*(4), 612–638.

Stone, D. (2005). *Decision-making in medieval agriculture.* Oxford: Oxford University Press.

Walker, J. T. (2015). National income in Domesday England. In M. Allen & D. Coffman (Eds.), *Money, prices and wages: Essays in honour of Professor Nicholas Mayhew* (pp. 24–50). London: Palgrave Macmillan.

Wareham, A. (2005). *Lords and communities in early medieval East Anglia.* Woodbridge: Boydell Press.

A Summary statistics of estimation sample

Table A1: **Summary statistics main variables**

Variable	**Mean**	**Median**	**Variance**	**10th percentile**	**90th percentile**
Value	5.0	2.0	93.7	0.5	12.0
Labor: non-slaves	14.4	9.0	355.5	2.0	31.0
Labor: slaves	2.1	1.0	12.8	0.0	6.0
Capital: ploughs	5.4	3.0	54.5	1.0	11.0
Land: ploughlands	5.8	4.0	62.5	1.0	12.0
Land: soil suitability	1.9	2.0	0.5	1.0	3.0

Table A2: **Main tenant-in-chiefs by number of manors**

Tenant-in-Chief	**Manors**				**Lords**	
	Number		**Value**		**Number**	**Share main (%)**
	Total	**Demesne**	**Total**	**Demesne**		
Count of Mortain	675	88	1,810.4	637.5	193	6.6
King William	470	359	8,379.7	6,156.1	149	1.0
Bishop Odo of Bayeux	328	23	2,121.2	506.9	145	7.9
Bishop of Coutances	226	25	755.5	194.9	116	27.1
Earl Roger of Shrewsbury	217	43	1,463.5	611.2	138	7.4
Count Alan	188	51	761.1	440.0	79	6.7
Baldwin the sheriff	167	19	340.0	127.9	90	5.3
Countess Judith	153	41	591.5	351.9	71	5.7
Henry of Ferrers	138	51	431.8	198.5	51	5.7
Roger of Bully	118	65	261.2	170.5	32	8.2
Robert of Stafford	110	15	217.1	73.1	67	4.3
Iudhael of Totnes	100	13	151.2	68.0	58	26.7
Bishop of Lincoln	98	19	730.3	312.6	78	7.0
Earl Hugh	97	20	516.6	133.8	38	11.9
Hugh of Grandmesnil	97	34	369.0	190.0	31	11.0
Average	15.8	6.7	81.4	47.5		

The summary statistics for the lords are calculated under the assumption that these lords are all separate individuals.

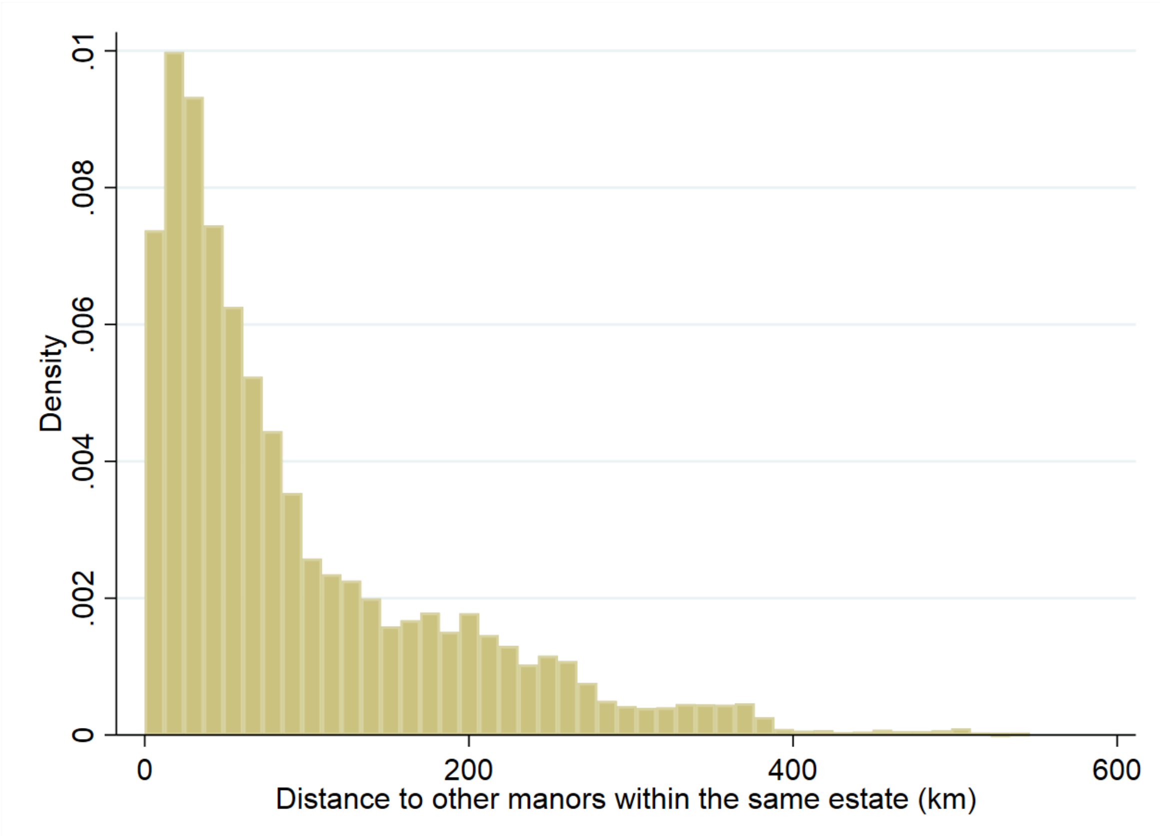
Table A3: **Main lords by number of manors (excluding demesne)**

Lord	**Manors**		**Tenant-in-chiefs**	
	Number	**Value**	**Number**	**Main (share in %)**
Drogo son of Mauger	70	80.7	2	Bishop of Coutances (98.6)
Reginald of Vautortes	48	71.8	1	Count of Mortain (100.0)
Ralph of Pomeroy	41	26.0	5	Iudhael of Totnes (40.9)
Alfred the butler	41	148.1	3	Count of Mortain (95.1)
Urso of Abetot	40	107.7	12	Abbey of Westminster (30.2)
Richard son of Turolf	36	40.1	5	Count of Mortain (82.1)
William of Keynes	35	96.1	3	Count of Mortain (91.9)
Wadard of Cogges	34	117.2	3	Bishop Odo of Bayeux (91.2)
Ilbert of Lacy	32	99.8	3	Bishop Odo of Bayeux (57.4)
Adam son of Hubert	28	239.4	1	Bishop Odo of Bayeux (100.0)
Nigel Fossard	28	28.9	1	Count of Mortain (100.0)
Hugh of Bolbec	27	122.5	3	Walter Giffard (78.8)
Reinbert the sheriff	26	85.3	2	Count of Eu (92.3)
Hamelin of Cornwall	22	21.9	1	Count of Mortain (100.0)
Turstin the sheriff	22	65.2	2	Count of Mortain (95.5)
Average including unidentified lords	1.6	9.9	1.1	(97.3)
Average excluding unidentified lords	3.2	16.9	1.4	(90.0)

For manors that have multiple lords, the complete value of the manor was attributed to every lord. As a result, the values in this table should be interpreted as an upper bound.

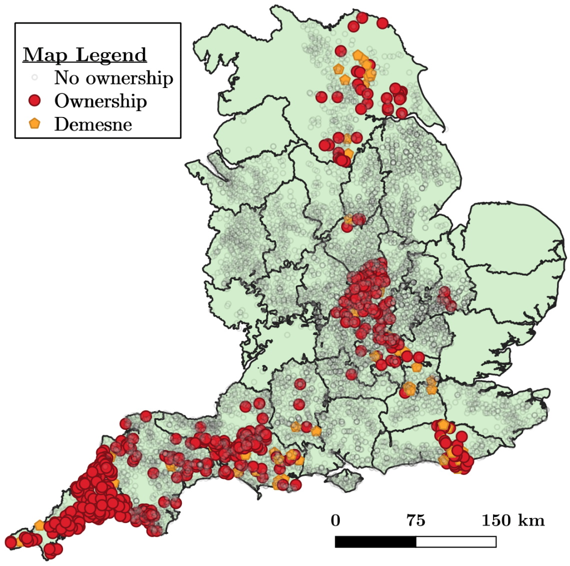
The average including the unidentified lords is calculated under the assumption that these lords are all separate individuals.

Figure A1: **Histogram of the distances to manors within the same estate**

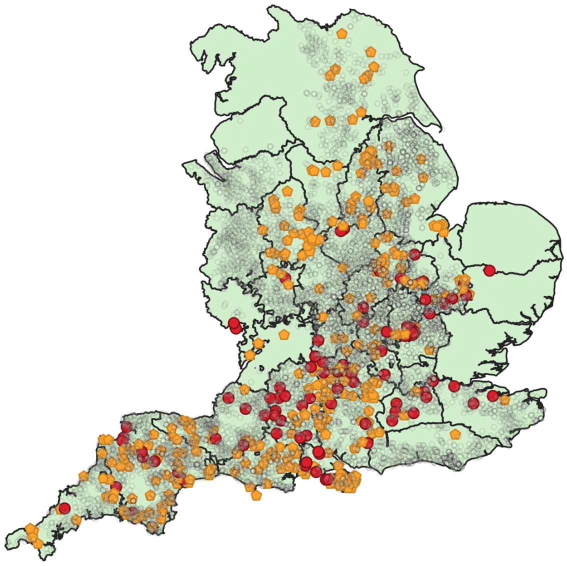


B Maps depicting manors of the main tenant-in-chiefs and lords

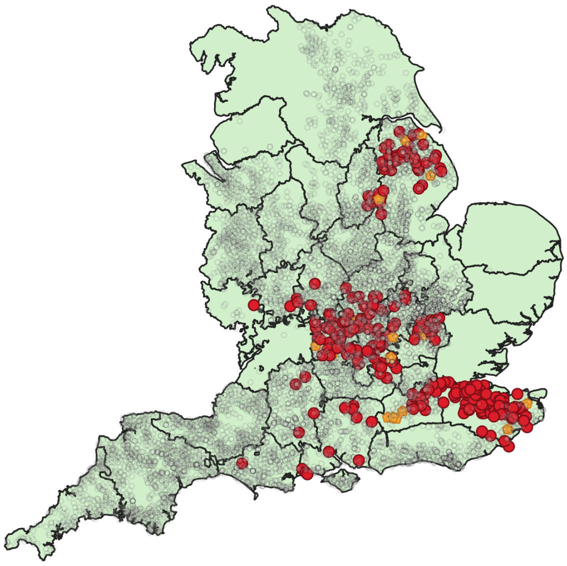
Figure A2: **Main tenant-in-chiefs by number of manors**



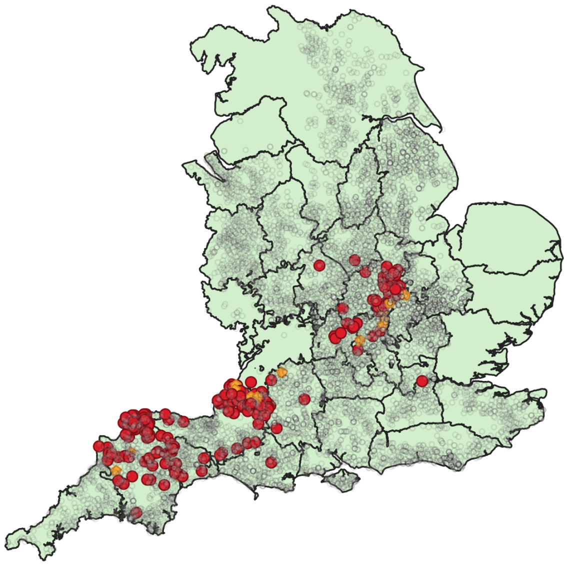
(a) Count of Mortain



(b) King William

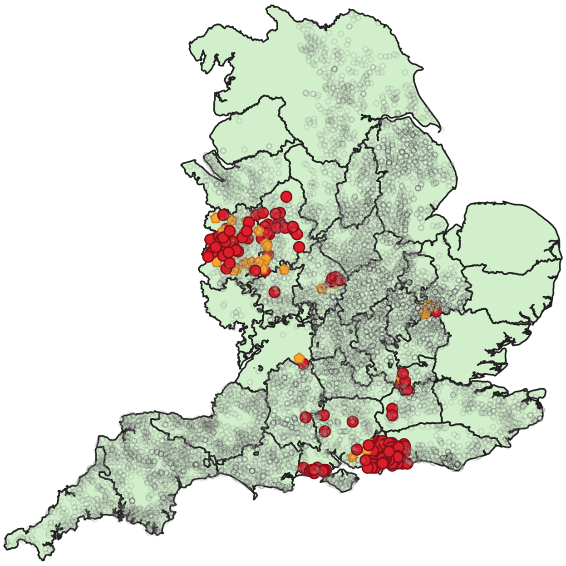


(c) Bishop Odo of Bayeux

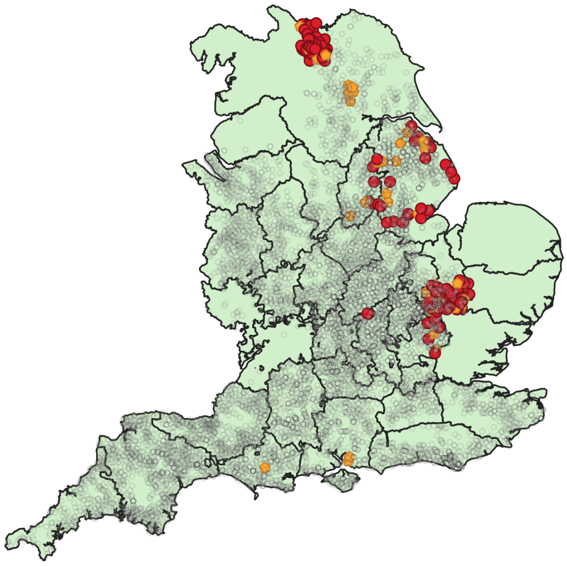


(d) Bishop of Coutances

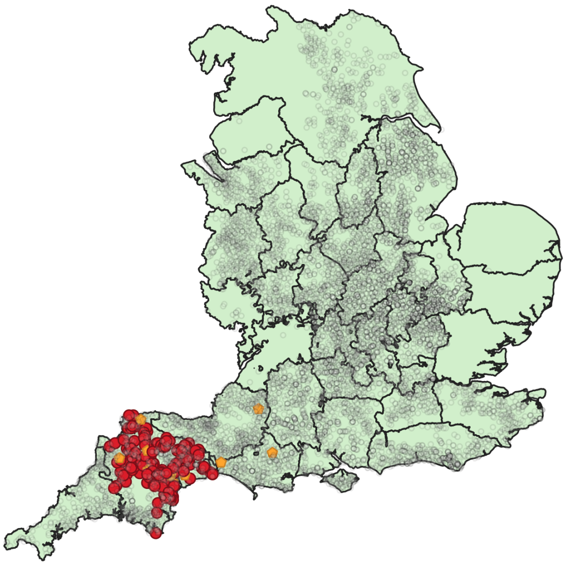
Figure A2: **Main tenant-in-chiefs by number of manors (continued)**



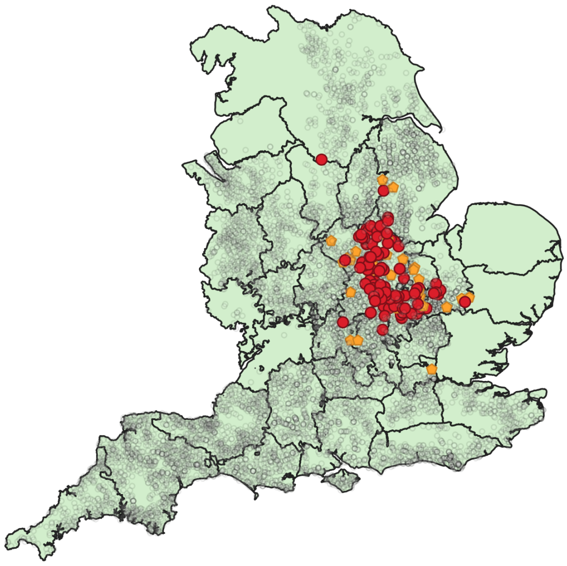
(e) Earl Roger of Shrewsbury



(f) Count Alan



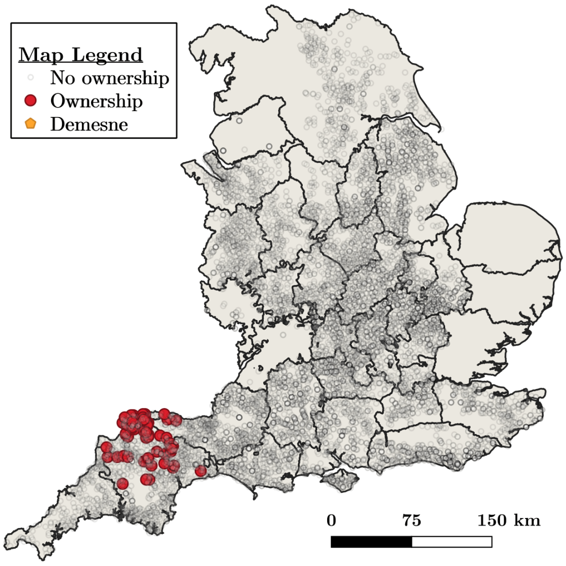
(g) Baldwin the sheriff



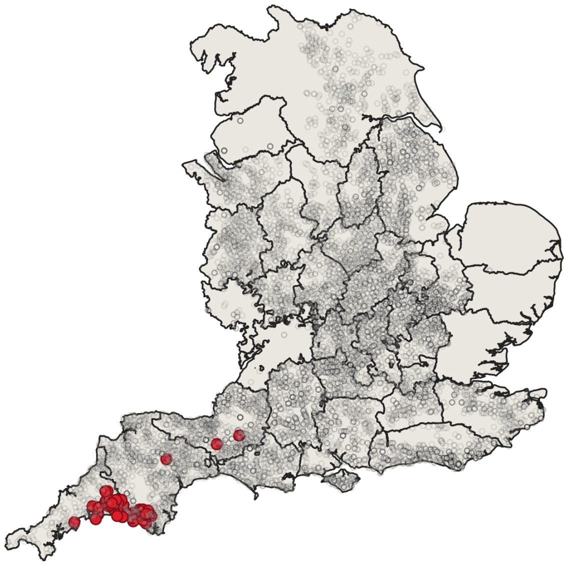
(h) Countess Judith

Source: Palmer (2010); historical county borders from Brookes (2017)

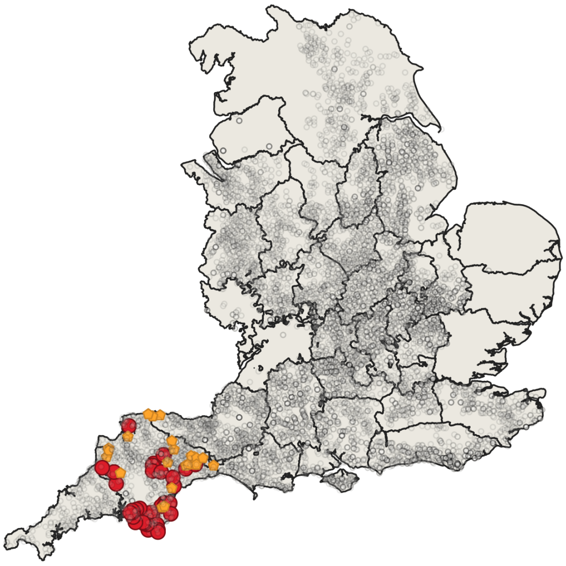
Figure A3: **Main lords by number of manors**



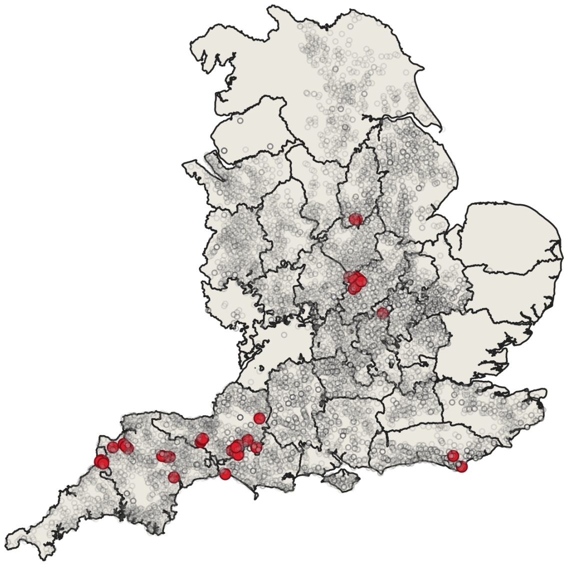
(a) Drogo son of Mauger



(b) Reginald of Vautortes

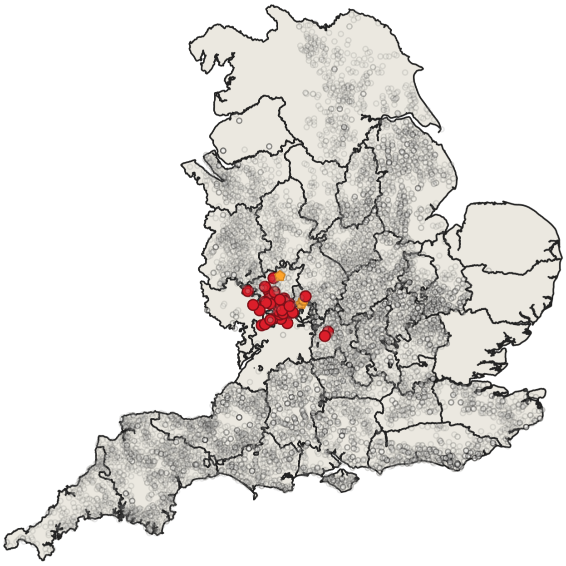


(c) Ralph of Pomeroy

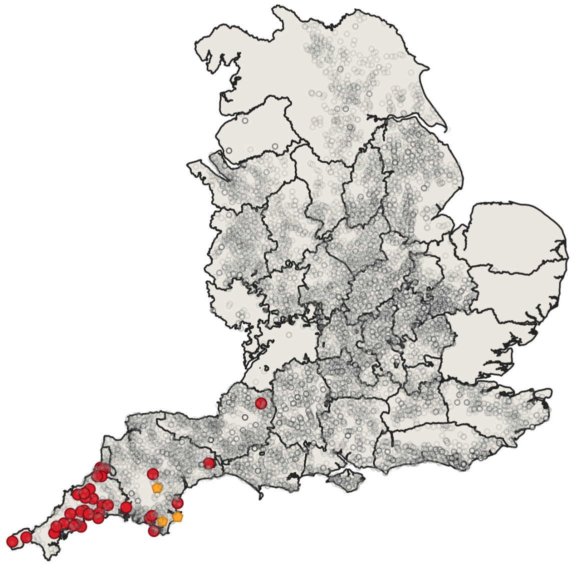


(d) Alfred the butler

Figure A3: **Main lords by number of manors (continued)**

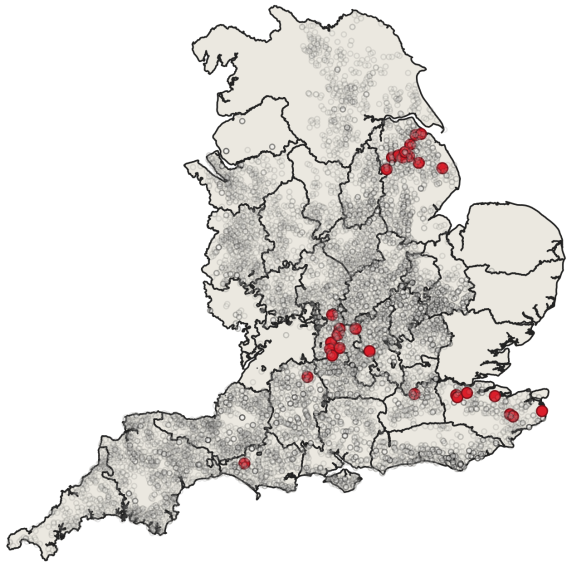


(e) Urso of Abetot



(f) Richard son of Turolf

(g) William of Keynes



(h) Wadard of Cogges

Source: Palmer (2010); historical county borders from Brookes (2017)

C Model with only productivity spillovers

As an alternative model, we consider the model that only contains productivity spillovers. Formally, we have

$$y_i = \alpha + \mathbf{x}_i \boldsymbol{\beta}' + \varepsilon_i, \quad \varepsilon_i = \lambda_F \frac{\sum_{f \in \mathcal{F}_i} \varepsilon_f}{|\mathcal{F}_i|} + \lambda_G \frac{\sum_{g \in \mathcal{G}_i} \varepsilon_g}{|\mathcal{G}_i|} + \eta_i, \quad \mathbb{E}[\eta_i \mid \mathbf{X}, \mathbf{F}, \mathbf{G}] = 0,$$

in which $\boldsymbol{\beta}$ denotes the direct effect of the manor's resources. λ_F (λ_G) captures spillovers in productivity from feudal (geographic) neighbors.[48] Stacking observations, this model can be rewritten compactly in matrix notation:

$$\mathbf{y} = \alpha \boldsymbol{\iota} + \mathbf{X}\boldsymbol{\beta}' + \boldsymbol{\varepsilon}, \quad \boldsymbol{\varepsilon} = (\lambda_F \mathbf{F} + \lambda_G \mathbf{G})\boldsymbol{\varepsilon} + \boldsymbol{\eta}, \quad \mathbb{E}[\boldsymbol{\eta} \mid \mathbf{X}, \mathbf{F}, \mathbf{G}] = 0, \tag{3}$$

where $\mathbf{F}$ and $\mathbf{G}$ are row-normalized adjacency matrices as defined in the main text. As this model is a special case of our full structural model, it can also be estimated consistently and efficiently by using the generalized spatial two-stage least squares (GS2SLS) procedure, as proposed by Kelejian and Prucha (2010) and Drukker et al. (2019).

Table A4 presents the estimates for this model. Overall, we find large positive and statistically significant results for the productivity spill-over parameters in all specifications considered. The estimates are somewhat higher than those of the full model, although the overall qualitative assessment remains intact. The main takeaway from these estimates is that feudal peers' unobserved agricultural performance had a significant positive effect on a manor's value. This effect is sizeable, albeit smaller than the impact of a manor's geographic neighbors.

[48] A sufficient condition for this model to have a stable and unique solution is that $|\lambda_F| + |\lambda_G| < 1$.

Table A4: **Estimates baseline econometric model (GS2SLS)**

Parameter			**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Labor: non-slaves		β_1	0.19***	0.15***	0.15***	0.17***	0.15***	0.15***
			(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Labor: slaves		β_2	0.11***	0.09***	0.09***	0.10***	0.09***	0.10***
			(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Capital: ploughs		β_3	0.54***	0.60***	0.57***	0.56***	0.59***	0.57***
			(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Land: ploughlands		β_4	0.13***	0.15***	0.15***	0.13***	0.14***	0.14***
			(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Constant		α	-0.25***	-0.21***	-0.17***	-0.18***	-0.20***	-0.17**
			(0.02)	(0.03)	(0.03)	(0.03)	(0.04)	(0.07)
Productivity spill-overs	**F**	λ_F	0.81***		0.43***	0.55***		0.46***
			(0.01)		(0.07)	(0.02)		(0.02)
	G	λ_G		0.93***	0.71***		0.75***	0.63***
				(0.01)	(0.01)		(0.02)	(0.03)
County FE						YES	YES	YES
Soil FE						YES	YES	YES
Observations			9,084	9,084	9,084	9,084	9,084	9,084
ADE productivity spill-overs			1.08	1.04	1.04	1.02	1.02	1.04
ATE productivity spill-overs			4.06	5.65	10.71	2.17	3.44	8.90

Note: Standard errors are in parentheses.
$*** : p < 0.01, ** : p < 0.05, * : p < 0.1$

D The role of within and between estate effects

Table A5: **Estimates of within and between estate contributions (GS2SLS)**

Parameter			**(1)**	**(2)**
Labor: non-slaves		β_1	0.15***	0.15***
			(0.01)	(0.01)
Labor: slaves		β_2	0.09***	0.10***
			(0.01)	(0.01)
Capital: ploughs		β_3	0.58***	0.57***
			(0.01)	(0.01)
Land: ploughlands		β_4	0.14***	0.14***
			(0.01)	(0.01)
Constant		α	-1.01***	-0.68***
			(0.03)	(0.05)
Productivity spill-overs	**F**	λ_{F_W}	0.21***	0.19***
			(0.02)	(0.02)
		λ_{F_B}	0.20***	0.19***
			(0.04)	(0.03)
	G	λ_G	0.63***	0.51***
			(0.02)	(0.03)
Scale spill-overs	**F**	δ_{F_W}	0.03***	0.04***
			(0.01)	(0.01)
		δ_{F_B}	0.08***	0.08***
			(0.01)	(0.01)
	G	δ_G	0.51***	0.28***
			(0.02)	(0.03)
County FE				YES
Soil FE				YES
Observations			9,084	9,084

Note: Standard errors are in parentheses.
$*** : p < 0.01, ** : p < 0.05, * : p < 0.1$

E Test for network endogeneity

In this section, we conduct a graphical test for network endogeneity based on the discussion in Boucher and Fortin (2016). In the presence of homophily, one can test the null hypothesis of network exogeneity by means of the joint distribution of the errors of our structural model and the errors of a model of network formation.

We first extend our structural model as

$$\begin{aligned}\mathbf{y} &= \alpha\boldsymbol{\iota} + \mathbf{X}\boldsymbol{\beta}' + (\delta_F\mathbf{F} + \delta_G\mathbf{G})\mathbf{y} + \boldsymbol{\varepsilon} \\ \boldsymbol{\varepsilon} &= (\lambda_F\mathbf{F} + \lambda_G\mathbf{G})\boldsymbol{\varepsilon} + \boldsymbol{\eta} \\ \boldsymbol{\eta} &= \rho\boldsymbol{\zeta} + \boldsymbol{\xi},\end{aligned} \tag{4}$$

in which $\mathbb{E}[\boldsymbol{\xi} \mid \mathbf{X}, \mathbf{F}, \mathbf{G}] = 0$. Note that when $\rho = 0$, the model collapses to our main model. In a second step, we assume that the feudal links are formed by means of a dyadic model of network formation

$$f_{ij} = \mathbb{I}\left(\kappa - \sum_k \varphi_k |x_{k,i} - x_{k,j}| + \tau g_{ij} - \mu|\zeta_i - \zeta_j| + \nu_{ij} \geq 0\right), \tag{5}$$

where ν_{ij} is an i.i.d. logistic error term.[49] When $\{\phi_k\}_k, \mu > 0$, we say the network exhibits homophily, as manors that have similar observed characteristics $\{x_k\}_k$ and unobserved characteristics ζ are more likely to form links. When $\tau > 0$, manors that are close to each other are more likely to form feudal links.

Unless $\rho = 0$ or $\mu = 0$, the estimates of the structural model are biased, as unobserved characteristics ζ influence both network formation and productivity. However, in this setup endogeneity has some testable implications that can be exploited to test the null hypothesis of exogeneity. The graphical test is implemented as follows:

1. We estimate the structural model, assuming that $\rho = 0$. From the estimates of this model, we can calculate $\widehat{\eta}_i$ for all manors i. For every pair of manors (i, j), we define $\widehat{\eta}_{ij} = |\widehat{\eta}_i - \widehat{\eta}_j|$.

2. We estimate the dyadic model using logistic regression, assuming that $\mu = 0$. We denote the predicted value of f_{ij} as $\widehat{f_{ij}}$.

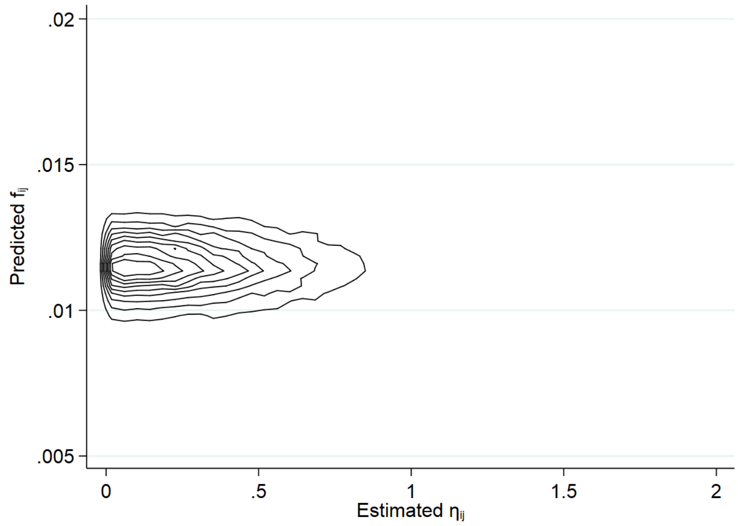
[49] Dyadic means that feudal links are formed independently.

3. We estimate the joint distribution of $\widehat{\eta}_{ij}$ and $\widehat{f}_{ij}$ for the subsample of unlinked manors, i.e. $f\left(\widehat{\eta}_{ij}, \widehat{f}_{ij} \mid f_{ij} = 0\right)$, and for the subsample of linked manors, i.e. $f\left(\widehat{\eta}_{ij}, \widehat{f}_{ij} \mid f_{ij} = 1\right)$, using nonparametric kernel density methods. If these joint distributions are similar, the null hypothesis cannot be rejected.

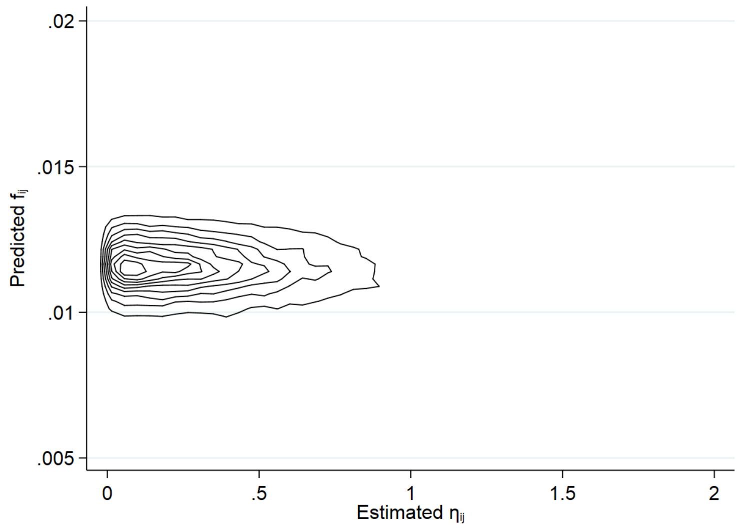
The underlying idea can be explained as follows. In the presence of endogeneity (i.e. $\mu, \rho > 0$), a pair of manors (i, j) that has a high predicted link value $\widehat{f}_{ij}$ but is unlinked in the data should have a large value for $|\zeta_i - \zeta_j|$ and hence for $|\eta_i - \eta_j|$. The opposite is true for pairs of manors that have a low predicted link value but are linked in the data. If there would be no endogeneity ($\mu = 0$ or $\rho = 0$), the residuals $\widehat{\eta}_{ij}$ would not provide any information on the probability that a link is created.

We inspect the joint distribution of $\widehat{\eta}_{ij}$ and $\widehat{f}_{ij}$ using nonparametric kernel density methods. Figure A4 provides estimates for both unlinked and linked pairs of manors. Since the joint distributions are rather similar, one might conclude that in our case, network endogeneity is not a substantial issue.

Figure A4: **Test for network endogeneity (KDE)**



(a) Kernel density plot for $f_{ij} = 0$



(b) Kernel density plot for $f_{ij} = 1$

F Robustness checks

Table A6: **Estimates of imputing IDs of unidentified lords (GS2SLS)**

Parameter	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Labor: non-slaves	0.19***	0.15***	0.15***	0.17***	0.15***	0.15***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Labor: slaves	0.12***	0.09***	0.09***	0.10***	0.09***	0.10***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Capital: ploughs	0.55***	0.60***	0.58***	0.56***	0.59***	0.57***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Land: ploughlands	0.12***	0.14***	0.14***	0.13***	0.14***	0.14***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Constant	-0.34***	-0.47***	-0.91***	-0.29***	-0.49***	-0.62***
	(0.03)	(0.05)	(0.03)	(0.03)	(0.05)	(0.06)
λ_F	0.82***		0.39***	0.47***		0.38***
	(0.02)		(0.04)	(0.03)		(0.03)
λ_G		0.92***	0.65***		0.62***	0.51***
		(0.03)	(0.02)		(0.03)	(0.03)
δ_F	0.07***		0.10***	0.09***		0.10***
	(0.02)		(0.01)	(0.01)		(0.01)
δ_G		0.17***	0.44***		0.21***	0.25***
		(0.03)	(0.02)		(0.03)	(0.03)
County FE				YES	YES	YES
Soil FE				YES	YES	YES
Observations	9,084	9,084	9,084	9,084	9,084	9,084

Note: Standard errors are in parentheses.
$*** : p < 0.01, ** : p < 0.05, * : p < 0.1$

Table A7: **Estimates when excluding manors with unidentified lords (GS2SLS)**

Parameter	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Labor: non-slaves	0.21***	0.16***	0.16***	0.18***	0.16***	0.16***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Labor: slaves	0.12***	0.09***	0.09***	0.10***	0.09***	0.10***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Capital: ploughs	0.55***	0.60***	0.58***	0.56***	0.59***	0.58***
	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Land: ploughlands	0.12***	0.14***	0.14***	0.13***	0.14***	0.14***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Constant	-0.37***	-0.52***	-0.92***	-0.30***	-0.51***	-0.67***
	(0.03)	(0.05)	(0.04)	(0.03)	(0.06)	(0.06)
λ_F	0.76***		0.38***	0.42***		0.35***
	(0.02)		(0.04)	(0.03)		(0.03)
λ_G		0.89***	0.62***		0.54***	0.43***
		(0.03)	(0.02)		(0.04)	(0.04)
δ_F	0.08***		0.09***	0.09***		0.09***
	(0.02)		(0.01)	(0.01)		(0.01)
δ_G		0.19***	0.42***		0.22***	0.26***
		(0.04)	(0.02)		(0.03)	(0.03)
County FE				YES	YES	YES
Soil FE				YES	YES	YES
Observations	7,045	7,045	7,045	7,045	7,045	7,045

Note: Standard errors are in parentheses.
$*** : p < 0.01, ** : p < 0.05, * : p < 0.1$

Table A8: **Estimates when including manors with multiple locations (GS2SLS)**

Parameter	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Labor: non-slaves	0.20***	0.16***	0.16***	0.17***	0.16***	0.16***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Labor: slaves	0.12***	0.09***	0.09***	0.11***	0.09***	0.10***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Capital: ploughs	0.53***	0.59***	0.57***	0.55***	0.59***	0.57***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Land: ploughlands	0.13***	0.15***	0.15***	0.14***	0.15***	0.15***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Constant	-0.36***	-0.45***	-0.90***	-0.30***	-0.49***	-0.64***
	(0.03)	(0.05)	(0.04)	(0.03)	(0.05)	(0.06)
λ_F	0.80***		0.40***	0.47***		0.38***
	(0.02)		(0.04)	(0.02)		(0.03)
λ_G		0.93***	0.66***		0.63***	0.52***
		(0.03)	(0.02)		(0.03)	(0.03)
δ_F	0.08***		0.10***	0.09***		0.10***
	(0.02)		(0.01)	(0.01)		(0.01)
δ_G		0.15***	0.43***		0.21***	0.25***
		(0.04)	(0.02)		(0.03)	(0.03)
County FE				YES	YES	YES
Soil FE				YES	YES	YES
Observations	9,488	9,488	9,488	9,488	9,488	9,488

Note: Standard errors are in parentheses.
$*** : p < 0.01, ** : p < 0.05, * : p < 0.1$

Table A9: **Estimates when using distances of 10km, 50km, and 100km (GS2SLS)**

Parameter	$d = 10$**km**	$d = 20$**km**	$d = 50$**km**	$d = 100$**km**
Labor: non-slaves	0.15***	0.15***	0.16***	0.16***
	(0.01)	(0.01)	(0.01)	(0.01)
Labor: slaves	0.10***	0.10***	0.10***	0.10***
	(0.01)	(0.01)	(0.01)	(0.01)
Capital: ploughs	0.57***	0.57***	0.57***	0.56***
	(0.01)	(0.01)	(0.01)	(0.01)
Land: ploughlands	0.14***	0.14***	0.14***	0.14***
	(0.01)	(0.01)	(0.01)	(0.01)
Constant	-0.43***	-0.63***	-1.07***	-1.09***
	(0.05)	(0.06)	(0.09)	(0.08)
λ_F	0.36***	0.36***	0.36***	0.40***
	(0.03)	(0.03)	(0.03)	(0.03)
λ_G	0.39***	0.51***	1.02***	1.81***
	(0.02)	(0.03)	(0.04)	(0.32)
δ_F	0.10***	0.10***	0.11***	0.10***
	(0.01)	(0.01)	(0.01)	(0.01)
δ_G	0.10***	0.25***	0.54***	0.56***
	(0.02)	(0.03)	(0.06)	(0.05)
County FE	YES	YES	YES	YES
Soil FE	YES	YES	YES	YES
Observations	9,084	9,084	9,084	9,084

Note: Standard errors are in parentheses.
$*** : p < 0.01, ** : p < 0.05, * : p < 0.1$

Table A10: **Estimates when using binned distances (GS2SLS)**

Parameter	**(1)**
Labor: non-slaves	0.16***
	(0.01)
Labor: slaves	0.10***
	(0.01)
Capital: ploughs	0.57***
	(0.01)
Land: ploughlands	0.14***
	(0.01)
Constant	-0.28***
	(0.07)
λ_F	0.37***
	(0.03)
$\lambda_{G_{0-20}}$	0.50***
	(0.03)
$\lambda_{G_{20-50}}$	0.03
	(0.07)
$\lambda_{G_{50-100}}$	0.02
	(0.18)
δ_F	0.10***
	(0.01)
$\delta_{G_{0-20}}$	0.02
	(0.01)
$\delta_{G_{20-50}}$	0.04*
	(0.02)
$\delta_{G_{50-100}}$	-0.06**
	(0.03)
County FE	YES
Soil FE	YES
Observations	9,084

Note: Standard errors are in parentheses.
$*** : p < 0.01, ** : p < 0.05, * : p < 0.1$

Table A11: **Estimates when excluding the ploughlands variable (GS2SLS)**

Parameter	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Labor: non-slaves	0.19***	0.17***	0.17***	0.18***	0.17***	0.17***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Labor: slaves	0.14***	0.11***	0.11***	0.13***	0.11***	0.12***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Capital: ploughs	0.64***	0.69***	0.67***	0.65***	0.68***	0.66***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Constant	-0.34***	-0.52***	-0.83***	-0.25***	-0.50***	-0.64***
	(0.02)	(0.05)	(0.04)	(0.03)	(0.05)	(0.06)
λ_F	0.76***		0.41***	0.46***		0.40***
	(0.02)		(0.03)	(0.02)		(0.02)
λ_G		0.88***	0.64***		0.60***	0.50***
		(0.02)	(0.02)		(0.03)	(0.03)
δ_F	0.10***		0.08***	0.09***		0.10***
	(0.02)		(0.01)	(0.01)		(0.01)
δ_G		0.24***	0.42***		0.26***	0.30***
		(0.04)	(0.02)		(0.03)	(0.03)
County FE				YES	YES	YES
Soil FE				YES	YES	YES
Observations	12,222	12,222	12,222	12,222	12,222	12,222

Note: Standard errors are in parentheses.
$*** : p < 0.01, ** : p < 0.05, * : p < 0.1$