Cadasters and Economic Growth: A Long-Run Cross-Country Panel*

Michelle D'Arcy[†] Marina Nistotskaya[‡] Ola Olsson[§]

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Abstract

Since the transition to agricultural production, property rights to land have been a key institution for economic development. Cadasters are public records of land/property ownership that reduce transaction costs for private agents in land markets and strengthen the state's capacity to tax. Despite a large body of extant micro-level empirical studies, macro-level research on the evolution of formal land registration, and its importance for economic growth, has so far been lacking. In this paper, we present a novel data set on the emergence of state-administered cadasters for 159 countries over the last millennium. We also analyze empirically the association between the development of cadastral institutions and long-run economic growth in a panel of countries. Our findings demonstrate a substantive positive effect of the introduction of cadasters on modern per capita income levels. Lower transaction costs and greater revenues from indirect taxation are found to be important mechanisms.

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[†]Trinity College Dublin, darcym1@tcd.ie
[‡]University of Gothenburg, marina.nistotskaya@gu.se
[§]University of Gothenburg, ola.olsson@economics.gu.se

1 Introduction

At different times, and for different reasons, states have adopted records of land/real estate ownership: *cadasters*. These records provide states with the information they need to tax and also make ownership visible to economic agents in ways that reduce transaction costs, underpin security of tenure and enable the functioning of land/property and credit markets at national scale. As such, through a number of channels, the adoption or improvement of cadasters are important aspects of a country's institutional environment that may impact on economic growth and development.

This paper investigates the relationship between state-administered cadaster records (henceforth cadasters) and economic growth using a novel dataset on variation in cadasters within countries' contemporary borders. In consultation with a large interdisciplinary literature (Arruñada, 2018; Coase, 1960; FIG, 1995; Williamson & Enermark, 1996), we define a cadaster as a public record containing information on a) a land/real estate asset and b) the party that holds c) interests, that is, rights, restrictions and responsibilities, over the asset. In other words, a cadaster record contains three pieces of information: *what*, *who* and *which* (interest), contained in two interlinked documents: a description of a spatial unit and a description of individuals/organizations and their rights, restrictions and responsibilities (henceforth RRR) over the spatial unit.

We document the timing of the adoption, quality and extent of cadasters for 159 countries between 1000 CE and 2015, ranging from China's comprehensive cadastral records, already in existence in 1000, Sweden's reform of the 1530s and Vietnam's in the 1470s, to contemporary countries like the Republic of Congo, Turkmenistan and Haiti that by 2015 still had no cadaster. We also observe reversals where existing cadastral institutions have been either purposefully abandoned (as in the Ottoman empire (c. 1600) or Russia (c. 1650)) or destroyed in conflict (as in Cambodia and Laos in the 1970s). Our data include both fiscal cadasters, established for the purposes of taxation, and legal cadasters, which are focused on recording property rights (for a discussion on the distinction between fiscal and legal cadasters see Appendix A).

Using this data we find consistent positive effects of cadasters on growth. Throughout the paper, we adopt the baseline specification from Acemoglu et al. (2019)'s study on democracy and growth, featuring several lags of the dependent variable to control for pre-trends, and year and country fixed effects. After replicating their main results, we introduce our *Cadaster* indicator to their data and show that the coefficient for *Cadaster* is significant even after the inclusion of both institutional variables. When we calculate long-run effects, we find that a full cadastral reform is associated with a 51 percent increase in GDP levels in the long run, as compared to the 21 percent increase in GDP from the introduction of democracy. We then extend the period covered by using Bolt et al. (2018)'s ("Maddison") data on growth rates stretching back to medieval times for some countries. In our preferred specification, covering the 1950-2015 period, a transition from no cadastral system at all to a full cadaster (i.e. a mapped cadaster, covering the entire territory of the country) is associated with a 2.01 percentage point immediate increase in the level of GDP per capita. For a typical cadastral reform at a smaller magnitude of 0.3, our estimates imply an instantaneous increase in GDP per capita of 0.6 percent. The positive association during the period is strongest in Europe and Africa.

Our argument for why this relationship exists focuses on two main channels: *lower transaction costs* and *greater state capacity*. First, cadasters contain authoritative information about the assignment of property rights to land/real estate, and state-administered cadasters make this information publicly available.[1] In his foundational publication Ronald Coase (1960) argued that "well-defined" property rights require specification of "*who* holds *which* rights over *what* property" (Arruñada, 2018, 663). This information is particularly important for alienation (sale) of assets as it identifies the seller and makes clear to buyers whether or not there are encumbrances. Cadasters contain this information: they identify the land/real estate asset on which the rights are held; and link this to the individual/organization holding the rights and the content of the rights.[2] While *who* owns *what* can be known locally without a cadaster,[3]

[1] This is in contrast to private cadasters, which preceded and often existed in parallel to state-administered ones. For more information on private cadasters, see Appendix A.

[2] While registers can also capture this information, they do not always entail the delimitation of boundaries; and where they do – e.g. Torrens titling registers – we code these as cadasters.

[3] In medieval and early modern Europe, "who" owned "what" was generally known at the local level, and mortgage markets were able to function in the absence of cadasters within communities with insider information and/or within personal networks where social norms upheld trust (Muldrew, 2016). Financial intermediaries, such as lawyers in England (Van Bochove et al., 2015) and notaries in France (Hoffman et al., 2019) used their social embeddedness and personal networks to bridge the information and trust gaps between creditors and borrowers. However, as economies developed and became increasingly complex, more efficient and impersonal solutions were needed. For example, in England, in its assessment of the need for a national system of land

state-administered cadasters make this information more easily available to all economic agents, enabling more efficient economic exchange at scale between strangers and reducing transaction costs. Thus, cadasters may impact on economic growth through their role in enabling property rights to be clearly and publicly defined, which "is an essential prelude to market transactions" (Coase, 1988, 158) and hence to growth.[4]

Furthermore, cadastrification constitutes an act of formalization of property rights by the state which, as a well-established literature has argued, might be expected to lead to credit supply and investment demand effects. Formalization of property rights means that real estate assets can be used as collateral in credit applications, providing stronger security to creditors who become more willing to supply credit (Besley et al., 2012; De Soto, 2000). Formalization might also increase the confidence of holders of land/real estate that their assets will not be confiscated by public authorities or predated upon by strong neighbors, thus leading to a boost in consumption, physical capital investment, and investment in human capital (Galiani & Schargrodsky, 2010). It might further induce less productive land holders to sell their land or temporarily move to urban areas for modern sector wage employment (Valsecchi, 2014). Despite strong theoretical arguments about the positive effect of property rights on economic growth (for review see Besley & Ghatak (2010)), the empirical literature does not uniformly support this proposition when it comes to property rights to land (Deininger & Feder, 2009; Fenske, 2011; Place, 2009).

Second, cadasters may impact on economic growth through their effect on the state's capacity to tax and provide public goods (Besley & Persson, 2009, 2013; Dincecco & Katz, 2016), and to have the kind of "infrastructural power" (Mann, 1984) needed to uphold economic institutions in other ways (Acemoglu et al., 2016). From "cutting-board" registers in China in 1143 (Zhao, 1986) to the Napoleonic cadasters of the early nineteenth century (Kain & Baigent, 1992) and urban cadasters in contemporary Latin America (Bosch Llombart, 2007;

registration the report of the 1829 Real Property Commission recognized that in the absence of such a register the transfer of land was an expensive legal process (Howell, 1999, 367).

[4]We follow Lai et al. (2015)'s interpretation of Coase in arguing that "when the cost of enforcement is high, less than fully defined, but sufficiently clear, property rights can still be efficient" (p. 274). It implies that a shift from 'no cadaster' to 'a cadaster' is more important than an improvement in the quality of descriptions of the *what*, *who* and *which*. For example, a shift from verbal description of assets to their cartographic representation is less important than a shift from no cadaster to a cadaster even with a narrative description of the land/real estate assets. Our quantification of the quality of land descriptions, as discussed in Appendix A, reflects this.

Erba, 2008), cadasters have often been established for fiscal purposes. In both historical and contemporary settings, cadasters improved the state's capacity to tax by furnishing the state with authoritative information on taxable assets and who is liable (Nistotskaya & D'Arcy, 2018).[5]

We examine the effects of cadasters on economic growth through both transaction costs and state capacity as intermediate channels. First, using the World Bank's *Registering Property* indicators as a proxy for transaction costs, we find that cadasters have a negative association with the number of procedures, the number of days, and the cost associated with property registration among more than 140 countries. Controlling for country and year fixed effects, a typical cadastral reform results in around 29 fewer days of waiting for a registration certificate. As a further test of the transaction costs mechanism, we explore the impact of cadastral reforms within 19th-century Germany (Kingdom of Prussia) where two major waves of reforms were rolled out: one during the French occupation of the west in 1808 and then throughout Prussia in 1867. We find that cadastral reforms greatly increased the farm density per unit of farmland after reform in the west, potentially suggesting a more dynamic land market due to lower transaction costs, and that there was a strong reversal in this trend by 1882, arguably due to land consolidation as a result of a Coasean increased efficiency effect. Regarding taxation, we find, somewhat surprisingly, that the strength of cadastral institutions appears to have no impact on either property or direct taxes but a strong immediate effect on indirect taxation within countries. One plausible interpretation of this finding is that cadastral reforms increase households' effective wealth (which boosts consumption) and contribute to a formalization of businesses, both of which increase indirect tax revenue.[6]

Our research strongly relates to the literature on the impact of institutions, particularly

[5]Even where cadasters are established for fiscal purposes, they contain the same type of information – *what*, *who* and *which* – as in legal cadasters that can serve the assignment of property rights and transaction costs lowering purposes. For example, in Indonesia property tax receipts are used as proof of "indicative ownership" (Kelly, 2004), and the Japanese fiscal cadasters in Korea and Taiwan in the early 20th century had immediate effects on the land and mortgage markets (Yoo & Steckel, 2016). However, given the tax purposes of fiscal cadasters the level of accuracy in determining property boundaries, property areas and ownership data "need not be great" (Kent, 1988, 104, 106).

[6]Additionally we examined the impact of cadastral reforms on investment rates and the real interest rate to find that the investment ratio increases by about 1.1 percentage points five years after a full reform (Figure C2 in the Appendix. In an event study of a few countries with novel time series data on historical real interest rates since medieval times, we find that cadastral reforms are associated with substantial increases in the real interest rate in the United Kingdom and the Netherlands, suggesting a relatively strong boost in rural investment demand (Table C9 in the Appendix.

property rights, on economic development (Acemoglu et al., 2005; North, 1990). It builds on important, but geographically circumscribed studies, that have examined the cadaster – economic development link (Libecap & Lueck, 2011a; Yoo & Steckel, 2016).[7] Our paper contributes to the literature by being the first that explicitly studies the links between cadastral institutions and economic development in a cross-country setting.

To ascertain the causal effects of cadastral reforms on economic growth is challenging in many ways. A particular concern here is with the potential for endogeneity and omitted variables as the determinants of cadastral reform remain underexplored and something of a black box. For instance, cadasters could be introduced as part of a large package of reforms or after a crisis when GDP levels are already recovering. This is the case in our more detailed individual country-level analysis of France, the Netherlands, Sweden and Italy, discussed in Section 3. Despite controlling for pre-trends, we cannot rule out that our estimated impact of cadastral reforms to some extent captures general recovery effects from such crises.

Beyond these particular cases, the process of collecting the data has highlighted that cadastral reforms have been undertaken for a wide variety of reasons in different places and time periods – from fiscal imperatives related to war in early modern Europe to land redistribution as part of colonization in the New World and Africa, agrarian reform in nineteenth century Europe to donor driven initiatives in contemporary developing countries. In light of this variation, we interpret the evidence we find for correlations between cadasters and economic development as suggestive but not necessarily causal. We hope that, with further exploration of the determinants of cadastral reform, our data opens up the possibility of edging towards a deeper understanding of the relationship between property rights and development at the macro level.

The paper is organized as follows: Section 2 presents the new data, including the coding that guided its construction and general trends in the *Cadaster* indicator. Section 3 outlines our empirical strategy and reports the main results. In section 4, we carry out econometric analysis of a number of potential mechanisms linking cadastral reforms with economic growth.

[7] Libecap & Lueck (2011a) found that the differences in the quality of land descriptions (a state-mandated standardized system vs haphazard system, with reference to features of local geography and man-made structures) in the U.S. state of Ohio resulted in marked immediate and long-term differences in the number of land market transactions, mortgages and land value in favor of the former. Yoo & Steckel (2016) found that the Japanese fiscal cadasters in Korea and Taiwan in the early 20th century had a profound effect on land sales and the number of land parcels registered as collateral.

The last sections reflect on the limitations of the analysis and conclude with the take-home message of this research and avenues for future work.

2 The *Cadaster* Index

2.1 Constructing the Index

Cross-national empirical research on the effects of cadasters has been hampered by the scarcity of suitable indicators (Haldrup & Stubkjær, 2013). We address this empirical gap in the multidisciplinary literature by developing a new measure of the existence, quality and extent of state-administered cadastral records.

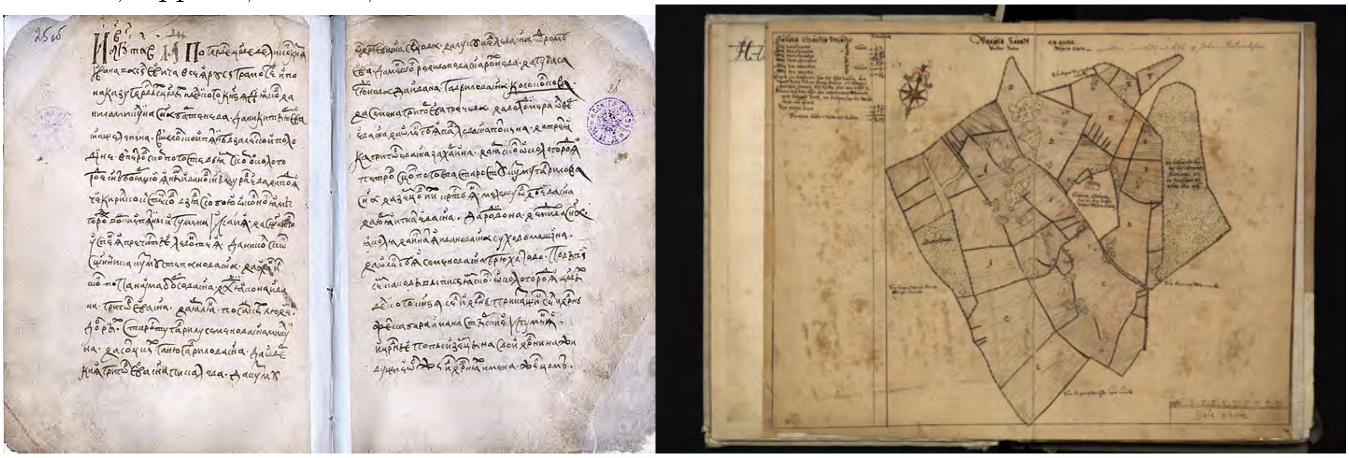
Cadasters are state (public) records, which contain two elements: a description of a land/real estate asset (*what*) and a description of a party (*who*) that holds interests – rights, restrictions and responsibilities (RRR) – over the asset. The (*what*) part contains information that uniquely identifies a land/real estate parcel – its location, dimensions and features – obtained through external observation, usually involving a survey. This information is linked with a record of individuals (or groups of people, such as communal groups or legal entities) and their rights and obligations with regard to the asset. Although the exact forms of land surveying and recording of rights have changed over time due to technological development, their essence – description of land/real estate assets and parties holding interests over those assets — has not, which has facilitated the creation of an indicator over a long period of time.

To create the *Cadaster* variable we assigned a score for each country/year, based on the answers to the following questions:

- "Was there a state-administered cadaster?" Country/year receives 1 point if "yes" and 0 points if "no", yielding score component 1 (z^1_{it});
- "Was the cadaster narrative or cartographic?". Country/year receives 1 if cartographic and 0.75 if narrative, yielding score component 2 (z^2_{it}); Figure 1 shows examples of narrative (left panel) and cartographic (right panel) cadasters;
- "How much of the country's territory was covered by the cadaster?". Country/year receives a score based on the proportion of the country's territory covered by the cadaster,

yielding score component 3 (z_{it}^3). If cadaster covers more than 90% of the territory, the coverage score is 1.

Figure 1: Left Panel: Narrative cadaster, Novgorod, Russia, 1571; Right panel: Cartographic cadaster, Uppsala, Sweden, 1635



Note: Images from Wikimedia Commons (nd) and The Swedish National Land Survey (*Lantmäteriet*).

These coding principles allow us to account for spatial and temporal change, including piece-wise increases due to reforms such as those in the United Kingdom,[8] as well as discontinuation of cadasters such as, for instance, in the Ottoman empire c. 1600 (Figure 2). The latter example demonstrates that it cannot be assumed that once commenced, cadastral institutions inevitably persist. Therefore, special care was taken in documenting the presence and attributes — type of cadaster and the spatial coverage — of cadasters at every t of the period. To this end, we used several hundred sources of information in different languages (for more information see Appendix A).

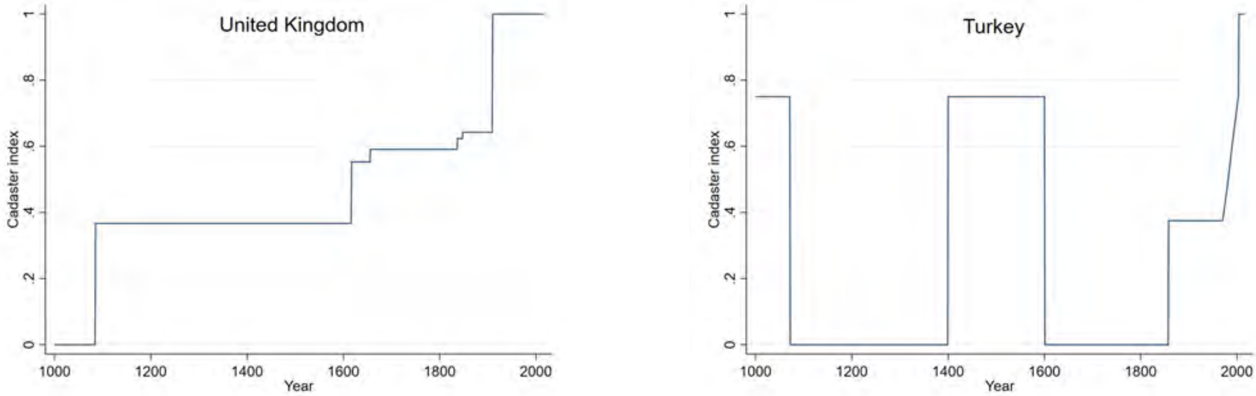
The coding principles went through a peer-review process (D'Arcy et al., 2019), and data was validated by the international association of land surveyors (FIG).

We compute the *Cadaster* indicator for every country/year by multiplying all three score components by one another:

$$Cadaster_{it} = z_{it}^1 \times z_{it}^2 \times z_{it}^3$$

[8] The cadastral history of the UK is one of the most complex, and England in particular constitutes an important exception to a cadaster-based system of properly defined and protected property rights to land. After the establishment of one of the earliest narrative cadasters in the Domesday Book (1085), the further development of a state-administered cadaster happened in different UK jurisdictions incrementally through the development of separate fiscal and legal cadasters. In England landed property was recorded through deeds registration and court arbitration. While this system was non-cadastral, in not describing land parcels, and therefore is not reflected in the cadaster score, it enabled well defined and protected property rights.

Figure 2: Evolution of *Cadaster* over time in United Kingdom and Turkey



Note: The figures show the evolution of *Cadaster* indicator, measured on the vertical axis, in United Kingdom (left panel) and Turkey (right panel) in 1000-2015.

The possible range of values is 0 to 1, where "0" stands for no state-administered cadaster at all and "1" stands for a mapped cadaster, covering at least 90 percent of the territory (henceforth a full cadaster).

Appendix A describes in detail the principles of coding and illustrates the coding process. Accompanying this paper is an online *Dates and Sources* Appendix – a 42,000 word document that provides a description of cadastral reforms in each country of the sample with supporting evidence for each relevant event.

As a validity check, we compare our *Cadaster* indicator with the commonly used World Bank *The Quality of Land Administration Index*, which consists of five indicators: reliability of infrastructure, transparency of information, geographic coverage, land dispute resolution, and equal access to property rights. We expect that our *Cadaster* indicator is positively associated with the index as a whole and its constituent parts. Since the last year for which *Cadaster* is available is 2015, we correlate it with the earliest available year 2016 from the Quality of Land Administration data.

Table C4 of the Appendix reports correlation coefficients. *Cadaster* has a positive and significant correlation with all constituent parts of the index but the correlation is strongest for the aggregated index *The Quality of Land Administration* (.75). Although not conclusive, this shows that our data is congruent with what less comprehensive but well-established data collection efforts have shown.

2.2 A Brief Look at the Data

Our new variable *Cadaster* codes the presence and extent of cadastral institutions in an annual panel that comprises 159 modern-day countries from 1000 to 2015.[9] We observe a considerable range in *Cadaster* scores. China has the earliest history of comprehensive cadasters: a nation-wide narrative cadastral survey took place in 2 AD and the first cartographic description of land assets was conducted in 1143 (Zhao, 1986, p. 69). In 1400 the Ottomans took over the practice of land records (*tahrir defterleri*) from the Byzantine empire, which kept land registers (*kodix*) from c. 995 AD (Gregory et al., 1991, p. 363), only to abandon it c. 1600[10] until the Ottoman Land Code of 1858, which re-instituted cadasters, but with a limited coverage. Sweden was the first European country to have a comprehensive mapped cadastre beginning in 1628 with considerable immediate and long-term benefits (Nistotskaya & D'Arcy, 2018).

Figure 3 depicts regional average levels of *Cadaster* from 1000 to 2015, revealing a number of interesting patterns. First, there is no meaningful cadastral development anywhere until the late medieval period when cadastral records begin to emerge in parts of Europe, Asia and the Middle East. This development plateaus in Asia from the 1600s to the 1800s, and falls back in Europe and the Middle East around 1600. While European scores begin to recover in the 1700s and increase consistently, the Middle East does not increase its score until the 1800s. The Western off-shoots rapidly increase their scores from the mid 1800s, quickly reaching maximum possible values, and at the end of the period their average score is higher than that of Europe. Africa and Latin America begin cadastrefication in the twentieth century, and are the world regions with the lowest *Cadaster* values presently.

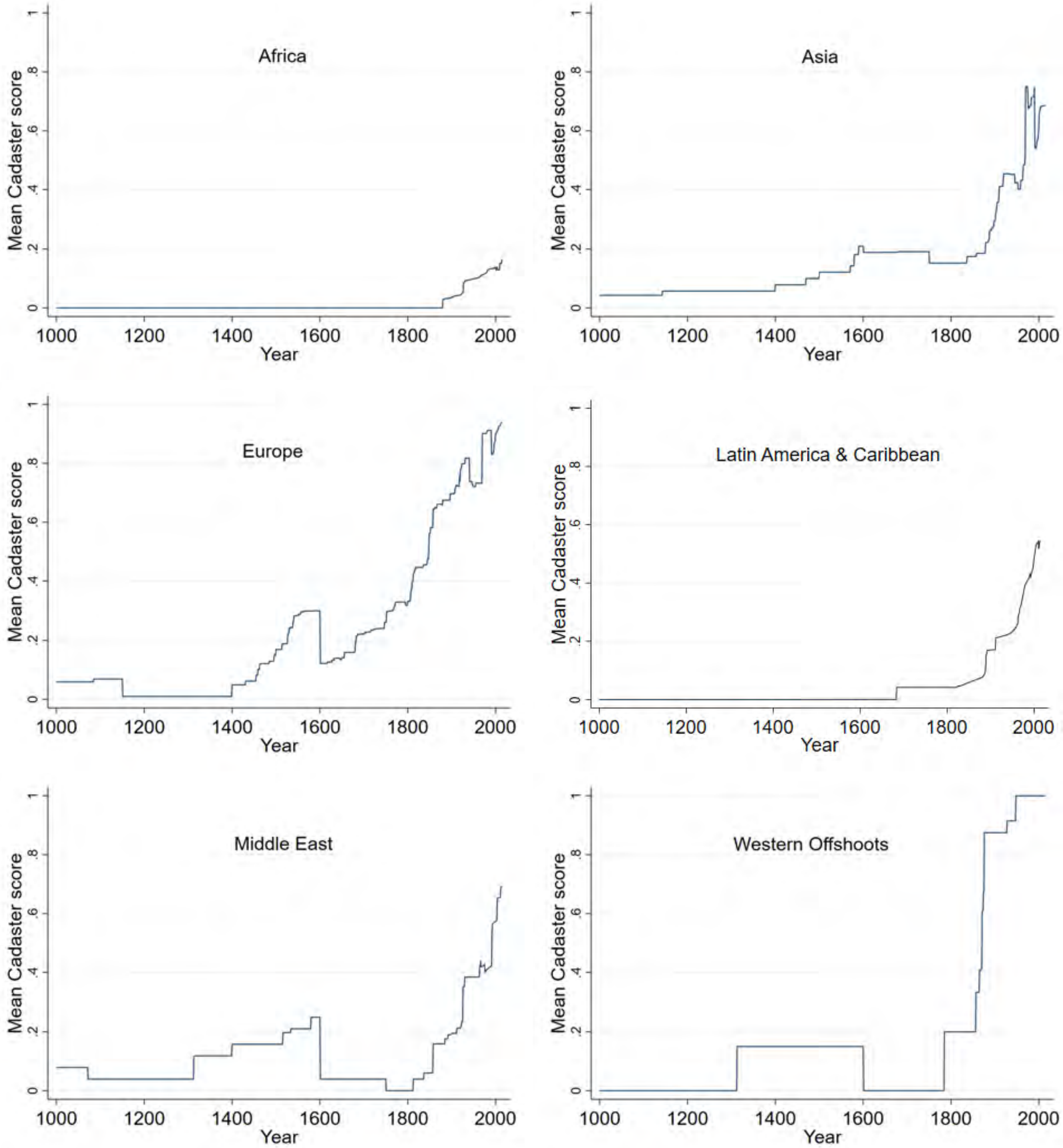
The summation of the *Cadaster* scores over all years for a country gives an indication of the country's accumulated cadastral experience.[11] Figure C1 in the online Appendix shows a histogram of the aggregated score for all countries over the 1000-2015 period. China and Egypt stand out with 980 and 613 years of total cadastral experience whereas the great majority of

[9]Our unit of analysis is countries in their present-day borders. For a discussion on borders endogeneity, please see (Borcan et al., 2018). Collecting data for the anterior period would require high research effort for low quality data due to the poor preservation of historical records. There are also very few examples of known cadasters before 1000.

[10]This explains the rise and fall of Cadaster scores in 1400-1600 for Europe, the Middle East and Western Offshoots observed in Figure 3 as the Ottoman narrative cadaster functioned in the territories of twelve modern-day European countries and seven other countries from the Middle East, Africa and Western Offshoots. Further information could be found in the codebook for our dataset.

[11]Such a measure can be compared to the aggregated *State history* measure in (Borcan et al., 2018).

Figure 3: Evolution of *Cadaster* over time across world regions



Note: The figures plot the mean levels of *Cadaster* for six world regions in 1000-2015. "0" indicates that no country in the region has a cadaster whereas "1" means that all countries in the region have a full cadaster. Western Offshoots include Australia, Canada, Israel, New Zealand and U.S.

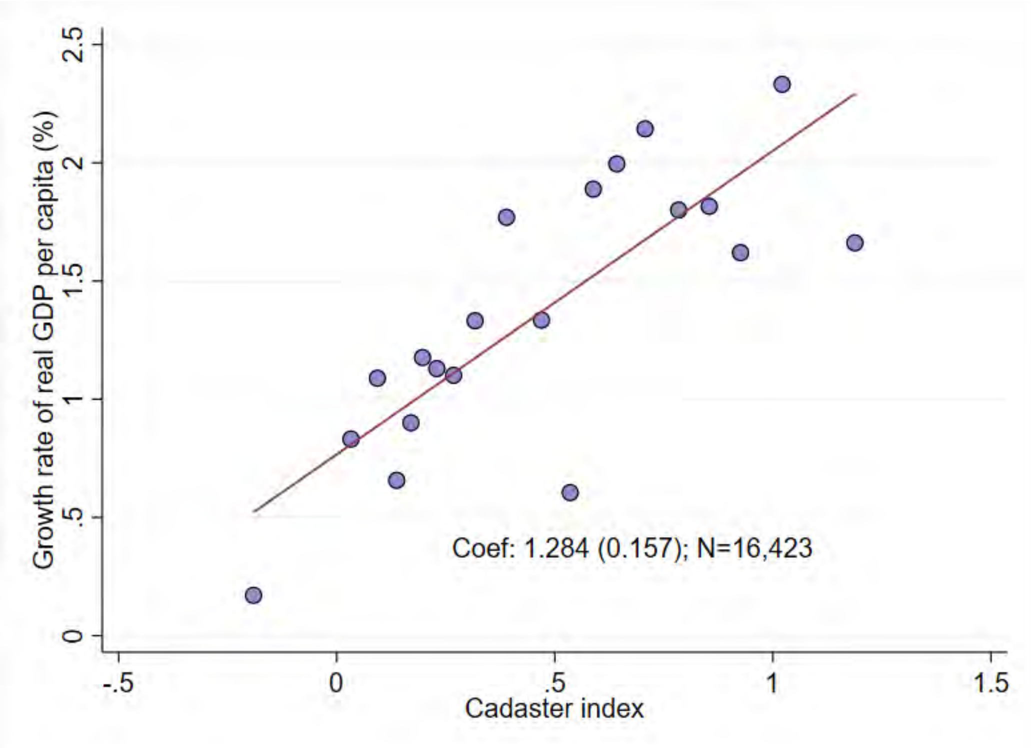
today's countries have a very short or no history of cadastral records. The median *Cadaster* aggregate score for the whole period is 48 years.

3 Empirical Analysis

In this section we analyze the quantitative relationship between the evolution of cadastral institutions and economic growth through history. We start by replicating Acemoglu et al. (2019)'s analysis without and with our *Cadaster* and comparing the impact of democratic versus cadastral reforms on GDP levels and growth rates. In section 3.3 we extend our analysis to a unbalanced cross-country panel over 1252-2015, using data from Bolt et al. (2018). In a robustness analysis, we introduce time-varying control variables and analyze heterogeneous effects across continents. Lastly, we perform an event study of the introduction of full cadastral reforms on growth in four countries with long time series: UK, France, Sweden and the Netherlands. Tables C1-C3 of the Appendix provide description of variables, data sources, and an overview of the temporal distribution of data availability.

3.1 Income Level Regressions

Figure 4: Conditional relationship between *Cadaster* and Growth Rate of GDP per capita for all available years



Note: The figure shows a bin scatter of a regression of *Cadaster* on *Growth of real GDP per capita*, controlling for a one-year lag of the *Log GDP per capita* for all available years. Estimated slope coefficient with standard error in parenthesis and the number of observations (N) are reported.

In order to provide an aggregated view of the association between cadastral institutions and growth, Figure 4 shows a bin scatter of the relationship between our *Cadaster index* and 16,423 available country-year observations of the growth of real GDP per capita, when controlling for the lagged level of initial income. The slope of the fitted line suggests that an increase in the *Cadaster* score from 0 to 1 is associated with a 1.28 percentage points higher GDP growth rate.

To examine these patterns further, we turn to a dynamic (linear) panel model for GDP per capita where we control for country and year fixed effects, as well as for trends in GDP levels before a cadastral reform, as our primary research design. Since such models can be specified in a number of different ways, we "tie our hands" by adopting the basic empirical strategy from Acemoglu et al. (2019).

Our econometric specification is given in equation (1) where y_{it} is the level of log GDP per capita in country i at time t and C_{it} is our *Cadaster* indicator. The α_i is a country fixed effect, absorbing the effect of time invariant country characteristics, such as geographical factors, δ_t is a time fixed effect, and ϵ_{it} is an error term that includes all time-varying effects on GDP per capita. We assume that past levels of y_{it} and C_{it} are orthogonal to ϵ_{it}. Note that we would expect that δ_t captures worldwide time-specific effects (for instance, an international downturn in the business cycle). We also include up to $L = 8$ lags of the dependent variable in our regressions with γ_l being the estimated coefficient for lag $l \leq 8$. The lag structure is put in place in order to eliminate the residual serial correlation in the error term, but also to control for pre-trends to ensure that countries that experience a cadastral reform (i.e. a change in the level of C_{it}) are not on a different trend relative to other countries with similar historical levels of GDP in the recent past.

$$y_{it} = \beta C_{it} + \sum_{l=1}^{L} \gamma_{t-l} y_{it-l} + \alpha_i + \delta_t + \epsilon_{it} \tag{1}$$

The main parameter of interest in equation (1) is β, which we expect to be positive. When C_{it} changes from 0 to 1, β is the percentage change in GDP per capita in year t that results from that cadastral reform.

We estimate the long-term impact of cadastral reform (equality 2) as per Acemoglu et al.

(2019):[12]

$$Long - run = \frac{\beta}{1 - \sum_{l=1}^{L} \gamma_{t-l}} \quad (2)$$

We employ the *within*-estimator to estimate the impact of *Cadaster* on GDP per capita, using Acemoglu et al. (2019)'s data. This limits our analysis to a fairly short time period (1960-2010), but allows us to directly compare the estimates for *Democracy* and *Cadaster*. The main results are shown in Table 1.

As recently emphasized by Kelly (2019), several papers in the historical persistence literature potentially suffer from spatial autocorrelation in both dependent and main explanatory variables. In order to address this concern, we introduce the newly developed procedures suggested by Colella et al. (2020) to calculate Conley standard errors (assuming a radius of 2000 km) that simultaneously produces Heteroskedasticity Autocorrelation Consistent (HAC) standard errors with a linear decay in time. For the main variables of interest (*Democracy* and *Cadasters*), these corrected standard errors are displayed in []-parentheses below the regular standard errors.

Columns (1)-(2) of Table 1 replicate the analysis in columns (1) and (3) from Table 2 in Acemoglu et al. (2019). Column (3) reports the estimates of the same model as in column (2) but calculated on the sample for which *Cadaster* is available. When we introduce *Cadaster* in columns (4)-(5), its coefficients are substantially higher that those of democracy and significant at least at the 10-percent level. The Conley standard errors for *Cadaster*, corrected for spatial autocorrelation and HAC, are generally lower than the regular standard errors. The estimate in the main specification in column (5) implies that a full cadastral reform increases GDP per capita by 1.87 percent.

The reason why the estimates for *Cadaster* are quite high could be due to the fact that unlike *Democracy*, our *Cadaster* variable does not have a dichotomous character, but often moves step-wise between 0 and 1, as can be seen in Figure 3. In total, our data record 261 substantial changes in *Cadaster* (greater than or equal to an absolute change of 0.1 in either

[12] When, for instance, $\beta = 2$ so that a full permanent cadastral reform leads to an immediate increase in GDP by 2 percent, and if $\sum_{l=1}^{L} \gamma_{t-l} = .98$ after L years, then the long-run impact is estimated to be $2/.02 = 100$, i.e. the long-run effect is a doubling of GDP per capita compared to status quo.

Table 1: Effects of *Democracy* and *Cadaster* on GDP per capita, 1960-2010

	Dependent variable: Log GDP per capita								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Democracy	0.973***	0.787***	0.712***			0.814**	0.657***	0.201	0.272
	(0.294)	(0.226)	(0.240)			(0.321)	(0.238)	(0.414)	(0.313)
	[0.288]	[0.250]	[0.266]			[0.318]	[0.263]	[0.411]	[0.329]
Cadaster				3.011**	1.871*	3.455***	2.111*	3.097**	1.810
				(1.276)	(1.051)	(1.310)	(1.101)	(1.292)	(1.127)
				[1.064]	[0.815]	[1.130]	[0.851]	[1.081]	[0.855]
Democracy x								1.434**	0.895*
Cadaster								(0.687)	(0.497)
								[0.736]	[0.544]
y_{t-1}	0.97***	1.24***	1.23***	0.97***	1.23***	0.97***	1.23***	0.97***	1.23***
	(0.01)	(0.04)	(0.04)	(0.01)	(0.04)	(0.007)	(0.04)	(0.01)	(0.04)
y_{t-2}		-0.21***	-0.19***		-0.19***		-0.19***		-0.19***
		(0.05)	(0.05)		(0.05)		(0.05)		(0.05)
y_{t-3}		-0.03	-0.02		-0.02		-0.02		-0.02
		(0.03)	(0.03)		(0.03)		(0.03)		(0.03)
y_{t-4}		-0.04**	-0.05***		-0.05***		-0.05***		-0.05***
		(0.02)	(0.02)		(0.02)		(0.02)		(0.02)
Long-run	35.59**	21.24***	19.96**	107.87**	51.44*				
effect	(14.00)	(7.21)	(7.80)	(45.05)	(28.23)				
NT	6,790	6,336	5,365	5,825	5,393	5,748	5,355	5,735	5,342
Countries	175	175	145	145	145	145	145	145	145

Note: This table reports the within estimates of *Democracy* and Cadaster on log GDP per capita. The reported coefficients are multiplied by 100. Columns (1)-(2) replicate the analysis in columns (1) and (3), Table 2, from Acemoglu et al. (2019). Results in columns (3)-(9) are calculated from the same sample of countries for which Cadaster data is available. All models include country and year fixed effects. Standard errors, clustered at the country level, in ()-parentheses. *** p<0.01, ** p<0.05, * p<0.1. Conley and HAC-consistent standard errors, using a radius of 2000 km, in []-parentheses.

direction) and a drastic change from 0 to 1 has only happened on 40 occasions in history. The mean level of substantial change in the variable is around 0.3. Using the estimate in column (7), a typical cadaster reform, increasing the level of *Cadaster* by 0.3, would lead to an instantaneous increase in GDP per capita by 0.63 percent. The long-run effect in column (5) is a 51.44 percent increase in GDP per capita, which is more than double the effect of *Democracy* (19.96) in column (3).

Columns (6)-(7) in Table 1 report the results of a "horse race" between the two institutional variables.[13] Both *Democracy* and *Cadaster* remain significant and the coefficient for *Cadaster* is considerably higher. When we interact the two variables in columns (8)-(9), the individual estimate for *Cadaster* is only significant with regular standard errors in column (8) (but is significant also in column (9) if Conley standard errors were used instead), whereas the positive estimates for the interaction term in (8)-(9) suggest that cadastral reforms have a stronger effect on GDP levels in democratic societies.

3.2 Growth Regressions

Our second empirical strategy is to first-difference the income levels from Acemoglu et al. (2019) in equation (1) and run regressions with the growth rate of GDP per capita as the dependent variable. This is equivalent to allowing for GDP to have a unit root. The econometric equation that we employ is in equation (3). As before, we control for between 1-4 lags of the dependent variable, year and country fixed effects. The dependent variable is $y_t - y_{t-1} = \Delta y_t$ which is equivalent to an annual growth rate since y_t is the log of GDP.

$$\Delta y_{it} = \beta C_{it} + \sum_{l=1}^{L} \gamma_{t-l} \Delta y_{it-l} + \alpha_i + \delta_t + \epsilon_{it} \tag{3}$$

Table 2 reports the results from a standard within estimation procedure, presenting both regular and HAC-corrected, Conley standard errors for the main varibles of interest. Columns (1)-(2) replicate the analysis for *Democracy* in Table 3, columns (1) and (3) from Acemoglu et al. (2019)). Column (4)-(5) report the estimates for *Cadaster*, which are again higher and fairly stable throughout the table in the range 1.716-1.965, albeit estimated with less precision

[13] The Pearson correlation between the two is about 0.37).

than *Democracy*. Note however that once again, the Conley standard errors for *Cadaster* are generally lower but fairly close to the regular standard errors. In the main specification in column (5), a full cadastral reform increases the GDP growth rate by a sizable 1.72 percentage points. A comparison of the estimates of the effects of a full cadaster to those of a democratic transition in column (7) suggests that the impact of cadastral reform is higher (1.85 vs 1.15 percentage points respectively). A mean level of cadastral reform (0.3) is associated with an increase in growth rates by 0.52 percentage points.

The interaction term between the two variables of interest this time has an insignificant coefficient (columns (8)-(9)), but individually they enter statistically significant (except in (9)), suggesting that *Democracy* and *Cadaster* have separate and non-complementary effects on economic growth.

3.3 Long-Run Economic Growth

In the analysis above, we only considered the time period after 1960. Our data on cadastral institutions go back to 1000 CE but finding reliable data on economic growth for such a long period posits a great challenge. Two of the most commonly used databases on economic growth – the World Bank's *World Development Indicators* and the *Penn World Tables* – only go back at most to 1950. The standard source of data on long-run economic growth in the literature has been the time series data developed by Angus Maddison and his collaborators. The Maddison Project's database was updated in 2018, incorporating a number of new and revised time series of national income and growth levels over several centuries (Bolt et al., 2018).

As our outcome variable, we use annual real GDP per capita for all available years back to 1252 CE which is the first year with a consecutive country-year time series. This measure is available for an unbalanced panel with only a few time series available in medieval times and 153 country observations in 2015 (see Table C3 in Appendix for details about the temporal distribution of GDP data availability). The longest consecutive annual time series on GDP per capita levels are those of the United Kingdom (from 1252), France (1280), Sweden (1300) and the Netherlands (1348). The time series *RGDPNApc* follows the traditional methodology in previous versions of the Maddison data, where the growth rates of GDP per capita track the

Table 2: Effects of *Democracy* and *Cadaster* on the growth rate of GDP per capita, 1960-2010

	Dependent variable: Growth rate of real GDP per capita								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Democracy	1.028***	1.269***	1.182***			0.914***	1.115***	0.768**	1.029***
	(0.250)	(0.243)	(0.259)			(0.264)	(0.254)	(0.326)	(0.310)
	[0.241]	[0.256]	[0.273]			[0.261]	[0.268]	[0.332]	[0.322]
Cadaster				1.716*	1.720*	1.965**	1.855*	1.863*	1.774
				(0.936)	(1.028)	(0.977)	(1.065)	(0.991)	(1.084)
				[0.896]	[0.906]	[0.960]	[0.943]	[0.929]	[0.946]
Cadaster x Democracy								0.330	0.189
								(0.563)	(0.562)
								[0.590]	[0.560]
Δy_{t-1}	0.29***	0.26***	0.25***	0.28***	0.25***	0.28***	0.25***	0.28***	0.25***
	(0.04)	(0.04)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
Δy_{t-2}		0.06**	0.06**		0.07**		0.07**		0.07**
		(0.02)	(0.03)		(0.03)		(0.03)		(0.03)
Δy_{t-3}		0.02	0.04**		0.04**		0.04**		0.04**
		(0.02)	(0.02)		(0.02)		(0.02)		(0.02)
Δy_{t-4}		-0.03	-0.05***		-0.05***		-0.06***		-0.06***
		(0.02)	(0.02)		(0.02)		(0.02)		(0.02)
NT	6,642	6,178	5,229	5,681	5,249	5,620	5,219	5,607	5,206
Countries	175	175	145	145	145	145	145	145	145

Note: This table reports the within estimates of *Democracy* and Cadaster on the growth rate of GDP per capita for three different time intervals. The reported coefficient are multiplied by 100. Columns (1)-(2) replicate results in columns (1) and (3), Table 3 from Acemoglu et al. (2019). All models include country and year fixed effects. Standard errors, clustered at the country level, in ()-parentheses. *** p<0.01, ** p<0.05, * p<0.1. Conley and HAC-consistent standard errors, using a radius of 2000 km, in []-parentheses.

growth rates given in the National Accounts. Bolt et al. (2018) argue that *RGDPNApc* is the most suitable variable for studying the within-country variation in growth rates and we use it as our primary outcome variable.

Given very few country-year observations before 1900 CE, we divide up the sample in three periods that all end in 2015 but with three different starting years: 1252 (full sample), 1900 and 1950. In the tables ahead, we refrain from reporting Conley standard errors since the earlier tables showed that they were of a similar magnitude as the regular ones. Columns (1)-(2) in Table 3 show the results for the full sample with 16,423 country-year observations, ranging back to medieval times for a few countries. The estimates 0.60 and 0.55 indicate that income per capita increases by around 0.55-0.6 percent as an immediate result of the reform, but none of the estimates are significant.

Table 3: Effect of *Cadaster* on GDP per capita through history, 1252-2015

	Dependent variable: Log GDP per capita (Maddison)					
	1252-2015		**1900-2015**		**1950-2015**	
	(1)	(2)	(3)	(4)	(5)	(6)
Cadaster	0.600	0.555	1.941**	1.603**	2.747***	2.012**
	(0.538)	(0.497)	(0.842)	(0.698)	(1.023)	(0.789)
y_{t-1}	0.979***	1.047***	0.980***	1.136***	0.981***	1.182***
	(0.003)	(0.027)	(0.003)	(0.025)	(0.003)	(0.035)
y_{t-2}		-0.059**		-0.118***		-0.130***
		(0.024)		(0.030)		(0.044)
y_{t-3}		0.017		-0.021		-0.028
		(0.024)		(0.027)		(0.032)
y_{t-4}		-0.029*		-0.022		-0.050***
		(0.017)		(0.019)		(0.018)
NT	16,423	15,911	11,219	10,833	8,999	8,689
Countries	150	150	150	150	150	150

Note: This table presents the within estimates of *Cadaster* on log GDP per capita for three different time intervals, using Bolt et al. (2018). *Cadaster*'s coefficients are multiplied by 100. Estimates of all included lags of log GDP per capita are shown in all columns. Standard errors, clustered at the country level, are in parentheses. In each specification, we control for a full set of country and year fixed effects. Unbalanced panel including 150 countries. *** p<0.01, ** p<0.05, * p<0.1

In columns (3)-(4), we run the same regressions for the 1900-2015 period, with the sample shrinking to 11,219 and 10,833 country-year observations respectively, but it also means that we can follow the growth rates of many more countries (44 countries have GDP data for 1901). The estimates for *Cadaster* now rise substantially to 1.60-1.94 and become significant at the 5-percent level.

From the 1950s the GDP time series data is available for more than 120 countries. The estimates of β in columns (5)-(6) reach an even higher level in the range 2.01-2.75 in columns (5)-(6). Our main specification with $L = 4$ in column (6) has a statistically significant estimate of 2.01. The estimate implies that a typical cadastral reform at a magnitude of 0.3 is associated with a 0.6 percent increase in GDP per capita. In the equivalent specification in Table 1, column (5), covering a somewhat shorter interval (1960-2010), the estimate is 1.87.

In the Appendix, we also show the equivalent growth rate regressions in Table C5. Just as was the case with income levels as the dependent variable in Table 3, the estimates for *Cadaster* are consistently positive and significant from 1900 onwards when the growth rate of real GDP per capita is the dependent variable in Table C5.

3.4 Treatment Effects and Selection on Observables

The results above clearly indicate that cadastral reforms had a strong positive association with economic growth during the last century. An obvious question here is whether the results so far can be interpreted as causal. In particular, is it reasonable to view cadastral reforms as an exogenous 'treatment'? In this section, we address this issue by using a semiparametric estimation approach that recognizes selection into treatment as a function of observables.

In this analysis we focus only on transitions to full cadastral institutions ($Cadaster = 1$) and contrast that with situations when only a partial or no transition has been made ($Cadaster < 1$).[14] We refer to this dichotomous cadaster 'treatment' variable as $c_{it} \in \{0, 1\}$ to be distinguished from $C_{it} \in [0, 1]$ above, and our analysis aims to capture the average causal effect of a full reform ($c_{it} = 1$) in up to 150 countries in 1900-2015.[15]

It is well known that when using observational data where the treatment is not fully randomized, the difference in means consists of the sum of the *Average Treatment Effect on the Treated* (ATET) and a selection bias into treatment (Angrist & Pischke, 2009). In the context of our study, it means that we cannot rule out that cadastral reforms and economic growth are driven by the same underlying factors. In the analysis below, we study the treatment effect in year t on economic growth $s \geq 0$ years ahead; Δy_{it}^s. The treatment effect parameter is given by:

$$\beta^s = E(\Delta y_{it}^s(c_{it} = 1) - \Delta y_{it}^s(c_{it} = 0)|c_{it} = 1, c_{it-1} = 0) \quad (4)$$

Since we are focusing on countries that are transitioning to having a full cadaster, the

[14] Most often partial cadaster reforms preceded a full cadaster. For instance, in Sweden, a narrative cadaster, covering most of state, existed already in the 1530s, while the country transitioned to a full mapped cadaster in 1628.

[15] During 1900-2015, 51 transitions to a full cadaster occurred, fairly evenly spread across time and sometimes happening twice in the same country when a reform was followed by a reversal and then by a new reform. Nineteenth of these transitions could be matched with GDP data. A simple means comparison over the whole 1252-2015 period shows that $c_{it} = 1$ is associated with a 0.86 percentage points higher GDP growth rate per capita than in countries where $c_{it} = 0$, whereas the equivalent number for the post-1900 period is a 0.6 percentage points higher annual growth rate.

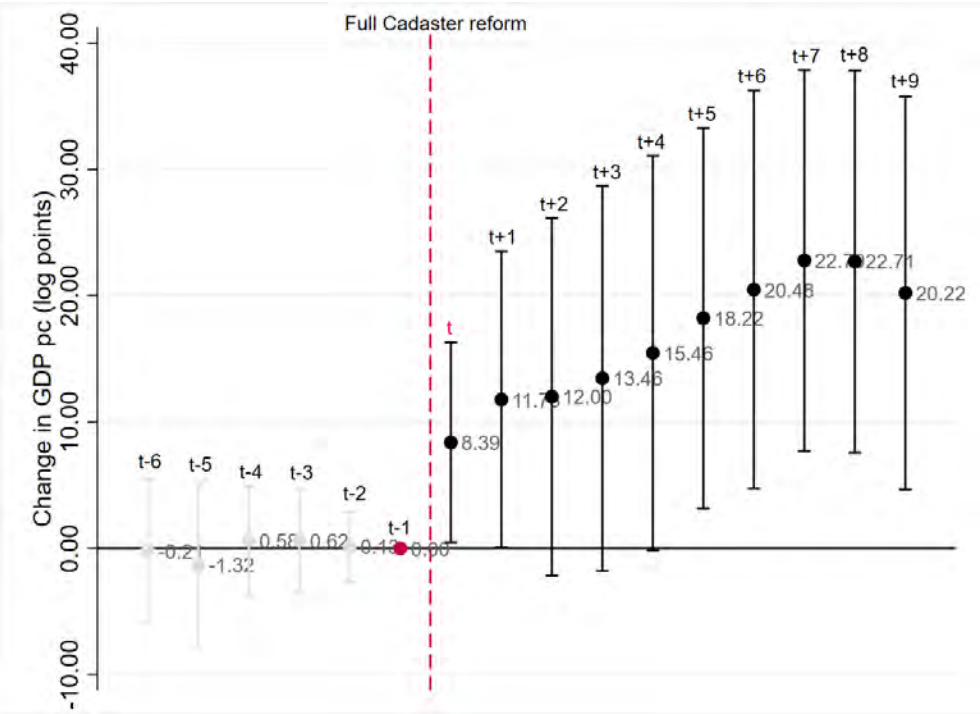
parameter above is equivalent to an ATET. Periods when cadastral institutions reversed are not included in the analysis. Furthermore, we recognize that the GDP dynamics and year fixed effects that we included as covariates in the within-estimations above, might affect selection into treatment, i.e. $c_{it} = 1$. In the analysis below, we model selection into treatment as a function of the standard set of observables from the previous analysis, i.e. $y_{t-1}, y_{t-2}, y_{t-3}, y_{t-4}, t$. We assume that no other factors simultaneously affect the propensity for cadastral reforms and economic growth. Note that we do not model how the specific functional form of the GDP dynamics, or the fixed and unobserved country characteristics, affect the dependent variable.

First, we first exploit a probit regression to estimate the propensity score of transitioning to full cadastral institutions (conditional on $c_{t-1} = 0$), using the standard set of observables. Table C6 in the Appendix shows the estimates from such 'first-stage' probit regressions. We then estimate the causal effect of cadasters on GDP by exploiting the inverse-propensity-score re-weighting (Acemoglu et al., 2019; Angrist & Kuersteiner, 2011), which gives greater weights to observations in the control group with a high propensity score for reform, but which did not experience a full cadastral reform. Such countries thus have a very similar GDP dynamic to the countries that actually had a full cadastral reform and therefore are a suitable control group.

Figure 5 shows the results of this exercise for $s = -6, -5, -4, ...+9$ with $s = 0$ corresponding to the year of full cadastral reform. We include the estimates six years prior to reform to check for differential pre-trends. The pattern in the figure clearly shows that the effects prior to the reform are close to zero, whereas there is an immediate and surprisingly strong positive treatment effect on the treated already in the treatment year. Specifically, GDP grew by 8.39 percent more in countries with a full cadaster than in countries without it, but which otherwise had similar trends in GDP. The estimate from this weighted regression on transition episodes to full cadastral institutions is notably higher than the within-estimates in the previous tables where we used our non-binary cadaster outcome variable. The β^s-estimate appears to peak after about 8-9 years when GDP in countries with a full cadaster is about 22.7 percent higher than in the control group. Given the relatively few episodes of a transition to full cadastral institutions during the period, the results should be treated with some caution.[16]

[16]Our analysis is similar Acemoglu et al (2019, section IV). In addition to inverse-propensity-score re-

Figure 5: Semiparametric estimates of ATET, 1900-2015



Note: The graph displays the semi-parametric estimates from a regression with reverse probability weighting (*teffects ipw* in Stata) where selection into treatment is modelled as a function of the standard four income lags and year FE from the within-estimations above. The dependent variable is the change in log GDP relative to $t-1$; $\ln y_{it+s} - \ln y_{it-1} = \Delta y^s_{it}$. The vertical axis shows the estimate as specified in equation 4. The estimates for $t+s$ are shown over the interval $s = -6, -5, ..0, 1..9$ where the coefficients for $s < 0$ checks for pre-trends. The thin vertical lines show 95-percent confidence intervals.

3.5 Robustness

In this subsection, we briefly check the robustness of our main long-run within-estimator results with respect to: (i) Whether the inclusion of binary indicators for full or no cadastral system changes the interpretation of our results (for a binary definition of cadastral reform, see also the previous section); (ii) whether the estimate of *Cadaster* remains significant when we include time-varying control variables commonly used in the literature; (iii) spatial parameter heterogenity in the effects of *Cadaster*.

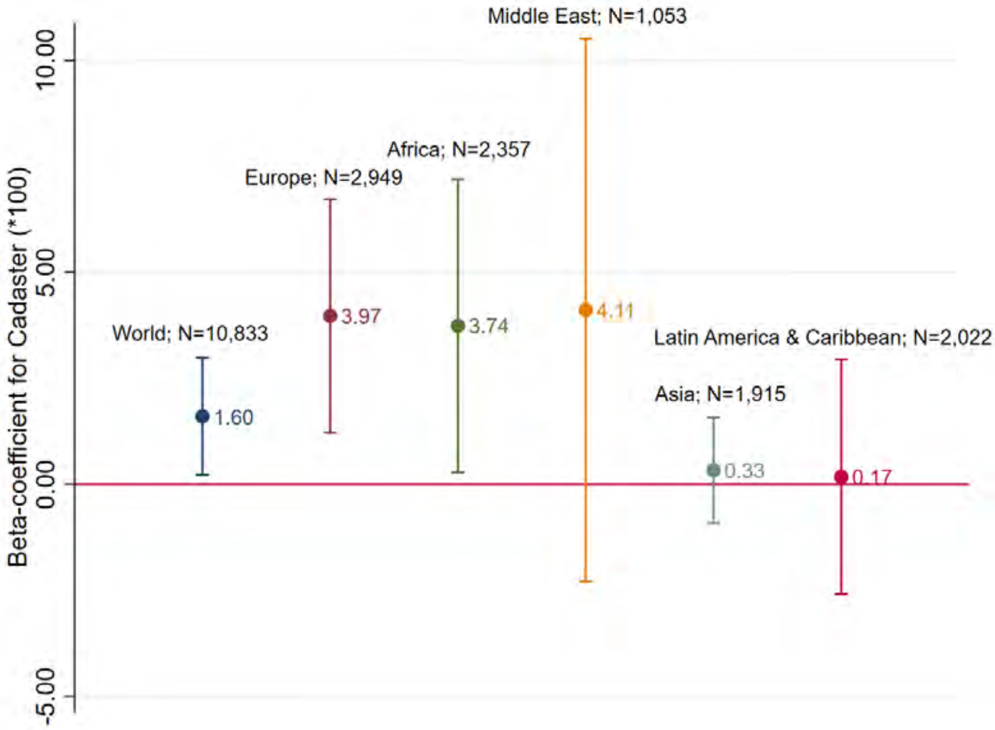
Table C7 in Appendix C reports the results of the first two exercises.[17] In brief, the table shows that the marginal effect of moving to a full cadaster (when *Cadaster*=1) is associated with a positive but lower estimate than for the ordinary measure and that having no cadaster

weighting, Acemoglu et al (2019, Table 5) also analyze linear regression adjustment and a doubly robust estimator. We include a larger sample of countries and a longer time period. Interestingly, their equivalent estimates for the 1960-2010 period indicate that the introduction of democracy gives rise to a 25 percent increase in GDP 20 years post-reform.

[17]Appendix C also includes more detailed discussion about the results in Table C7.

at all has an expected negative effect. The coefficient for *Cadaster* remains positive and stable throughout Table C7 when confounding variables for levels of democracy, population density, and public health are included.

Figure 6: Spatial parameter heterogeneity: Effect of *Cadaster* on GDP per capita across world regions, 1900-2015



Note: The graph presents the within coefficients of the effect of *Cadaster* on (log) GDP per capita for the world as a whole as well as for five macro regions. *Cadaster*'s coefficients are multiplied by 100. 95 percent confidence intervals are shown as vertical lines. The estimated specification includes four lags of log GDP per capita as in Table 3, column 4. The estimate for *World* is identical to that in Table 3, column 4. Standard errors are clustered at the country level. In each specification, we control for a full set of country and year fixed effects. Unbalanced panel including up to 150 countries. Total number of country-year observations (N) are shown in the graph.

Is the main tendency in the results spatially heterogeneous and driven by developments in particular parts of the world? To answer this question, we disaggregate the full sample for the 1900-2015 period into five macro regions (countries assigned as "Western Offshoots" are a reference category). Figure 6 displays the β-coefficients, number of country-year observations (N), and the associated 95 percent confidence intervals for regressions of real GDP levels per capita on *Cadaster* with specifications equivalent of that in column (4) Table 3, featuring four lags of the dependent variable, country and year fixed effects. The first estimate for the world as a whole is 1.60, which is significant at the 5-percent level and identical to the coefficient in Table 3, column (4). The coefficients for Europe and Africa are higher (3.97 and 3.74) and also significant at the 5-percent level. The other three estimates for the Middle East, Asia and Latin America and the Caribbean, are not significantly different from zero and the latter two have coefficients very close to zero.[18] Hence, it appears that the positive impact of cadastral reforms for the world as a whole is to a large extent driven by a positive association in Europe and in Africa.

3.6 Country Case Studies

Table 4 reports the results of an in-depth analysis of the four countries with the longest available time series for GDP per capita: the United Kingdom, France, Sweden, and the Netherlands. We estimate the impact of Cadaster on the annual growth rate of GDP per capita, using the preferred specifications in Tables 1-2, which include four lags of the dependent variable in order to control for pre-trends. Columns (2), (4), and (6) and (8) of Table 4 include linear time trends to filter out the effect of potential long-run trends in the growth rate within the period.

Table 4: Effect of *Cadaster* on the growth rate of GDP per capita in the UK, France, Sweden and the Netherlands, all available years

	Dependent variable: Growth rate real GDP per capita							
	UK 1252-2015		**France 1280-2015**		**Sweden 1300-2015**		**Netherlands 1348-2015**	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Cadaster	4.184***	4.186**	1.203*	1.303*	0.996	-2.616*	1.860**	2.926**
	(.879)	(1.860)	(.651)	(.685)	(.671)	(1.419)	(.733)	(1.371)
	[1.109]	[2.170]	n.a.	n.a.	[.633]	[1.287]	n.a.	n.a.
Δy_{t-l}, lags 1-4	✓	✓	✓	✓	✓	✓	√	√
trend		✓		✓		✓		✓
T	759	759	696	696	711	711	652	652
R^2	.14	.14	.09	.09	.04	.06	.08	.08

Note: This table reports the OLS estimates of the effect of *Cadaster* on the growth rate of GDP per capita in four countries. The *Cadaster* coefficients are multiplied by 100. All specifications include four lags of the dependent variable (not reported). Specifications in columns (2), (4), (6), and (8) include a linear time trend. Robust standard errors in ()-parentheses and Newey-West standard errors (four lags) in []-parentheses. Newey-West standard errors are not available for France and Netherlands due to missing data. *** p<0.01, ** p<0.05, * p<0.1 based on t-values from robust standard errors.

The results suggest that an increase of the *Cadaster* indicator from 0 to 1 is associated

[18] The null result for Latin America is particularly interesting, given that De Soto (2000)'s influential ideas about property rights originated in reference to Latin America. It may in part be explained by the predominance of fiscal rather than legal cadasters in this context.

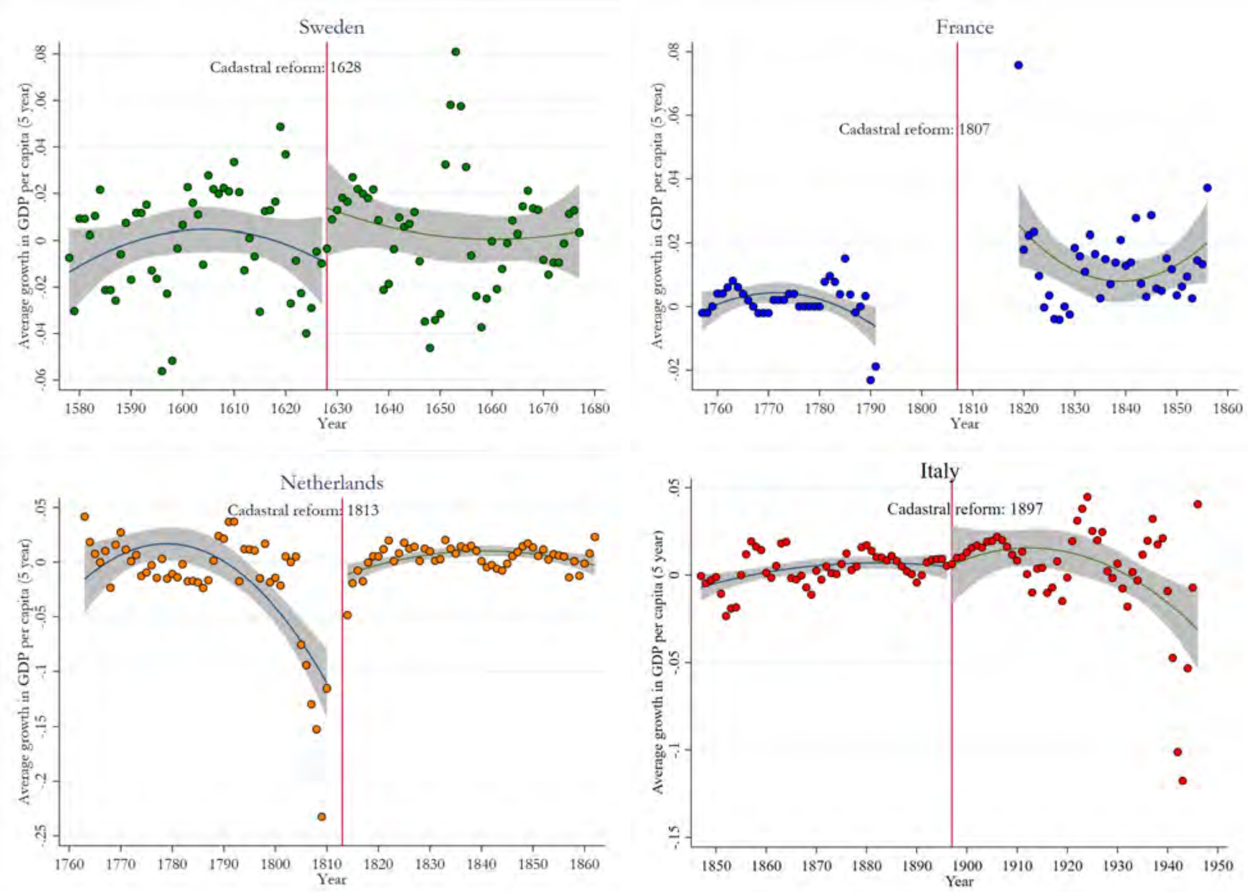
with a 4.18 percentage point increase in the growth rate for the UK. This is the strongest effect among the four countries under study, however given the UK's unorthodox history of state cadaster, this estimate should be interpreted with caution. The Netherlands displays the second strongest effect: the growth rate increases by 1.86-2.93 percentage points as a result of a full cadastral reform. In France, the *Cadaster* estimate is 1.2-1.3 and significant at the 10-percent level. In Sweden, the effect is unclear, as the estimate's sign changes once a time trend is accounted for.

Next, we examined the impact of a comprehensive cadastral reform in greater detail by conducting an event analysis. Figure 7 shows the development of the five-year moving average of growth rates of GDP per capita during a century-long window 50 years before and after the year a country achieves a full cartographic cadaster ($Cadaster = 1$). We have included non-linear fitted regression lines with confidence intervals at 5-percent level. In this analysis, we replaced the United Kingdom, which did not achieve a full cadaster until 1910, with Italy.

Figure 7 offers several noteworthy observations. First, in all four countries the reform was preceded by a falling trend in GDP per capita growth — a pattern similar to the one observed by Acemoglu et al. (2019) before democratic reforms. Hence, one cannot rule out that cadasters could have been introduced in response to economic hardships. In our full panel regressions, this issue is at least partially dealt with by including pre-trends in the form of lags of the dependent variable. Second, higher average growth rates after reform are found in all four countries, corroborating the findings in Table 2 and Table 3, columns (3)-(6).

Putting cadastral reforms in these four European countries in a broader historical context leads to further observations. First, in all countries except Italy, the reform was carried out in the context of frequent military conflicts between European states. In Sweden, the 1628 reform happened soon after Sweden's wars with Denmark and Russia, and when the country was embroiled in the Thirty Years War (1618-48). In France and the Netherlands, the reforms were carried out in the Napoleonic aftermath of the French Revolution. Second, cadastral reforms were accompanied by a cluster of other institutional reforms. For example, the transition from a narrative to a mapped cadaster in Sweden in 1628 was only one of several institutional innovations undertaken in this period, together with military, tax, legal and educational reforms (Roberts, 2014). Similarly, in France, the 1807 cadastral reform was carried out as part of

Figure 7: Event study of full cadastral reform on average GDP growth rate per capita during a 100-year window in Sweden, France, Netherlands, and Italy



Note: The figure shows event studies during a 100-year window of a full cadastral reform in Sweden, France, Netherlands, and Italy. The vertical axis is a five-year moving average of growth rates in GDP per capita. The figure shows fitted polynomial regression lines with 5-percent confidence intervals before and after the year of reform, indicated by a vertical line. France and Netherlands have missing growth observations around the time of the reform.

wide-ranging Napoleonic reforms, including a comprehensive legal code, standardization of measurements and weights, as well as administrative, tax, education, and military reforms. In the Netherlands, the reform of 1813 happened in the final years of the French dominance before the *United Kingdom of the Netherlands* was established in 1815 as an independent state at the Congress of Vienna. The long peace that ensued after Napoleon's defeat in 1815 also contributed to the higher post-reform growth rates in France and the Netherlands. In Italy, after unification was completed in 1871, the country underwent a period of significant political, economic and social reform, including the constitutional, electoral, judicial, administrative, educational and land reforms, which led to the rapid transformation of the agricultural sectors (Toniolo, 2014).

While cadasters were a critical institutional change with regard to the assignment and protection of property rights, this case study exercise advises against overinterpreting the causal nature of the impact of cadaster on economic growth. The drivers of cadastral reform in the European historical context were endogenous to broader state-building efforts, and beyond Europe, as discussed in the introduction, were very different. As a result, causal identification will always be challenging, and further research, in particular into the divergent drivers of cadastral reform, is needed.

4 Mechanisms

This section explores channels through which cadastral reforms could plausibly affect economic growth: *transaction costs*, *state capacity*, and *investment demand*. The evidence provides support for the transaction costs and state capacity mechanisms, indicating the need for further research to examine the mechanisms of influence in greater detail.

4.1 Transaction Costs

From a Coasean perspective, one of the key benefits of cadasters is that they reduce transaction costs, particularly those related to registering land/real estate, which is beneficial to output. We examine this conjecture using the World Bank's *Registering Property Indicators* (World Bank, 2022) as a proxy for transaction costs. These include the number of procedures, time (in days) and cost (percent of property value) associated with registering property (land or a building), assuming a standardized case of a limited liability company. The *Registering Property* data is available for 2005-2020 for up to 149 countries in our sample that have observations up to 2015. Hence, we can construct a panel with 11 years of country-year observations.

The basic empirical equation that we estimate in the sections on mechanisms is:

$$M_{it} = \beta C_{it} + \sum_{l=1}^{L} \omega_{t-l} M_{it-l} + \sum_{l=1}^{L} \gamma_{t-l} y_{it-l} + \alpha_i + \delta_t + \epsilon_t \tag{5}$$

The dependent variable M_{it} is one of our several mechanism variables. Most often, we include 1-4 lags of the dependent variable and of GDP levels y_{it}, in line with the main specification in the previous analyses. We also include combinations of country and year fixed effects as before. Our main focus is on the β-coefficients that estimate the within-country marginal impact of contemporary cadastral reforms on our intermediate variables.

Table 5: Effect of *Cadaster* on Transaction Costs, 2005-2015

	Dependent variable:					
	Procedures (#)		**Time(days)**		**Cost (% value)**	
	(1)	(2)	(3)	(4)	(5)	(6)
Cadaster	-1.031**	-0.320	-274.067***	-98.246***	-5.840***	-0.034
	(0.402)	(0.284)	(67.233)	(23.301)	(1.190)	(0.308)
Mean	6.07	6.07	64.04	64.04	6.14	6.14
Country FE	✓	✓	✓	✓	✓	✓
Year FE		✓		✓		✓
y_t, lags	0	1	0	1	0	1
M_t, lags	0	1	0	1	0	1
N	1,459	1,256	1,459	1,256	1,459	1,256
Countries	149	142	149	142	149	142

Note: The table reports the within-country estimates of the effect of *Cadaster* on measures of transaction costs for the 2005-2015 period. Unbalanced panel including up to 149 countries. Information about mean level in the dependent variables, number of lags of the dependent variable and of y_{it} and year fixed effects in each specification is included. Each specification includes (unreported) country fixed effects. Standard errors are in parentheses, clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1

Table 5 reports the estimates of *Cadaster* on three measures for transaction costs. Given the short time frame (11 years), every included lag leads to a decrease in the number of observations. In columns (1), (3), and (5), we therefore do not include any lags or year fixed effects, but only country fixed effects. In (2), (4) and (6), we include also year fixed effects and lags. The mean number of procedures required for registering property in columns (1)-(2) is 6.07. The estimate of β in column (1) suggests that a standard cadastral reform of 0.3 decreases the number of procedures by 0.31. However, when year fixed effects and lags of the dependent variable and of GDP levels are included (2), the *Cadaster*'s coefficient is not significant. A statistically significant and substantively important impact of *Cadaster* is revealed on the time cost of registering a property. In a model with a more demanding specification (4), the estimate implies that a typical cadastral reform of 0.3 is associated with 29 fewer days of waiting. Given that the mean is 64 days, the time cost of registration is almost halved following a typical cadaster reform.

This result may look extraordinary large, but is consistent with anecdotal evidence on the outcomes of recent cadastral reforms. For example, in Rwanda the time needed to register property decreased from 370 days before the reform (2007) to 80 days after the partial implementation of the reform (2009) and to 32 after completion of the nation-wide land titling program in 2013 (World Bank, 2022). Similarly, in Georgia, by the end of the national cadastrification program in 2005, the number of days to needed to register property was 9, compared to 40 for the years before.[19]

When we take the monetary costs of registration as the dependent variable in columns (5)-(6), the *Cadaster* estimate is negatively signed, but statistically significant only in the specification with country fixed effects (5), but not in column (6). This finding is also consistent with recent evidence, suggesting that despite successful cadastral reforms, such as in Rwanda, the statutory fees for land transactions remain high for many landlords, especially in rural areas (Ali et al., 2021). It was almost ten years after the completion of a full cadaster that an advocacy coalition was formed in Rwanda that started to lobby the government to reduce or scrap land transfer fees (Kanamugire, 2020). Considering the totality of the evidence, cadastral reforms seem to reduce transaction costs, but the effect of cadasters is likely to be heterogeneous for different types of transaction costs in terms of its timing and magnitude. Given the limitations of the data on transaction costs in land registration, our ability to examine this issue in depth is limited, and caution is warranted in drawing definitive conclusions from this exercise. Future research can build on our findings to examine the issue further.

In order to probe deeper into the transaction cost effects of cadasters, we studied the case of the evolution of cadastral institutions in the west and east of the historical Kingdom of Prussia in the 19th centruy. According to a Coasean logic, cadasters may a) lower transaction costs and lead to a more dynamic land market and b) also improve transferablility of property rights, enabling assets to flow to those who can use them most productively. We examine this proposition in the context of cadastral reforms and agricultural developments during the 19th century within the historical Kingdom of Prussia. In preview, our results suggest support

[19] The fact that the effect of cadaster is immediate is also consistent with historical research on the effects of Japanese colonial cadasters in Taiwan (1905) and Korea (1918). For example, the number of land parcels registered as changing hands through sale increased in Taiwan from 4,500 in 1905 to more than 51,000 in 1906; and the number of land parcels registered as collateral increased from under c. 4,800 in 1905 to almost 44,000 in 1906 (Yoo & Steckel, 2016, p. 639).

for the first argument - of cadastral reform leading to more market transaction - but weaker evidence for long-term land consolidation.

We focus on the effects of the cadastral reform in 1808 in the provinces of Rhineland and Westphalia and the country-wide reform in 1867 (Figure B1 in Appendix) on farm density per unit of farmland in east and west Prussia (Figure B2 in Appendix). Besides the timing of cadastral reform there was a distinction between the east and west of Prussia in terms of the underlying average farm size (larger in the east and smaller in the west) and land gains by the peasantry from emancipation reform in the early 19th century. This enables us to consider the effects of cadastral reform under different underlying land ownership distributions. Appendix B provides a more complete account of the historical background, and also data, results and interpretation of the Prussian analysis.

Following a Coasian logic suggests that cadastral reforms may have enabled peasants to become formal owners of land, leading to an increase in the number of registered farms in the short run through lower land conveyancing and other transaction costs. In the longer run, on the other hand, cadaster reforms may have lead to the consolidation of land (lower farm density). However, both processes may be of smaller magnitude in the east given that there were already fairly large farms before the cadastral reform and that emancipation did not turn the peasantry into landholders *en masse* as it did in the west.

We test these propositions by using data from the *Ifo Prussian Economic History Database* (iPEHD, 2021), which contains digitized information from Prussian historical censuses on the county level. We study the impact of cadastral reforms on farm density in 1816, 1858 and 1882. The first date, 1816, was right after the end of the Napoleonic Wars when the western provinces of Rhineland and Westphalia maintained the cadaster, imposed by Napoleonic France in 1808. The second date, 1858, was nine years before a Prussia-wide cadastral reform in 1867. The last census date, 1882, is fifteen years after the country-wide reform (see Figure B1).

Based on these three waves of census data, we construct a variable (log) *Farm density*, capturing the number of farms per sq km of farmland among 266 counties that were integral parts of the Kingdom of Prussia in 1816. We also create two dummies for cadastral reform: a dummy for Rhineland and Westphalia provinces that experienced a full cadastral reform already in 1808 and another dummy for the rest of the provinces that experienced a transition to a full cadaster in 1867. Figure B2 in Appendix depicts mean levels of Farm density in the western and eastern provinces over time. As can be seen, farm density was substantially higher in the west during the whole period, as noted in the literature (Kain & Baigent, 1992; Kopsidis & Wolf, 2012).

The empirical equation that we estimate is:

$$F_{ipdt} = \alpha_i + \beta C_{pt-\theta} + \gamma F_{ipdt-\tau} + \delta_d + \epsilon_i \tag{6}$$

In this log-linear specification, the outcome variable F_{ipdt} is log farm density in county i in province p in district ("regierungsbezirk") d in census year t. The main estimate of interest is β, capturing the marginal effect of a (treatment) dummy for cadastral reform, θ years prior to the census year in question, where cadastral reforms are defined at province level. We also control for farm density in the previous census τ years back in time, $F_{ipdt-\tau}$, and district fixed effects δ_d. The latter are included to account for unobserved local characteristics.

Table 6 reports the results. The dependent variable in column (1) is log *Farm density* in 1858, regressed on the equivalent measure in 1816, a treatment dummy for provinces that experienced a cadastral reform in 1808, and district fixed effects. The γ-estimate points to a very strong persistence as farm density in 1816 strongly predicts density in 1858. However, the significant β-estimate for the 1808 cadastral reform of 0.843 implies that provinces with cadasters had an 84.3 percent greater increase in farm density than non-reform provinces.

In columns (2)-(3), the dependent variable is log Farm density in 1882, more than a decade after German unification and the introduction of a full cadaster in the whole country. The 1867 cadaster dummy in column (2) now captures the impact only in the provinces that experienced a cadastral reform for the first time in 1867 (i.e. *not* Rhineland and Westphalia, which is the reference category). The estimate for cadaster in 1867 is significant in column (2). The result indicates that farm density in provinces that had a recent cadastral reform grew 54 percent faster since 1858 than provinces that had a cadastral reform back in 1808. In column (3), where we control for initial levels of farm density in 1816 and district fixed effects, the estimate for the 1808 cadaster dummy is negative but insignificant. Thus, the evidence for land consolidation in the west is therefore weaker and there is not evidence of an effect in the east.

Table 6: Effect of Cadastral Reforms on Farm Density in West and East Provinces of the 19th Century Kingdom of Prussia

	Dependent variable: Log Farm density		
	In 1858	**In 1882**	
	(1)	(2)	(3)
Cadaster in 1808	0.843***		-0.229
	(0.284)		(0.203)
Cadaster in 1867		0.541***	
		(0.185)	
Log Farm density in 1816	0.625***		0.533***
	(0.070)		(0.056)
Log Farm density in 1858		0.697***	
		(0.057)	
Constant	1.270***	0.544**	1.967***
	(0.171)	(0.230)	(0.078)
District FE	✓	✓	✓
Counties	266	266	266
R^2	0.92	0.84	0.80

Note: This table reports the estimates of the dummies for *Cadaster* reforms in 1808 and in 1867 on the (log) number of farms per sq km of total county farmland in 1858 and 1882. Initial levels of log farm density are included as controls. The sample is 266 counties that were part of the Kingdom of Prussia in 1816. All specifications include (unreported) district fixed effects. Heteroskedasticity-robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

One interpretation of these results is that the surges in farm density in the first few decades after the cadastral reform in the west and east were at least partially caused by lower transaction costs which also attracted new buyers of farmland. An interesting and important implication of this finding is that cadasters were not a barrier to productivity enhancing reforms such as enclosure.[20] A further implication is that the literature that has specifically considered the impact of reform in Prussia on productivity, has not sufficiently accounted for the impact of cadastral reforms - concerned with the identification of property rights - rather than tenure reform - concerned with the content of property rights. Existing literature has suggested that increasing productivity was a response to growing demand from industrial centers and not the

[20]Enclosure happened at a similar pace in settings with and without cadasters. In England enclosure happened in the absence of a state cadaster. However, Sweden was, after England, the European country that began the process of enclosure earliest and did so in the context of a cadastral system that was already centuries old. In Sweden enclosure (*storskifte*) was proposed by the head of the Swedish Land Survey Office, Jacob Faggot, in the 1750s and approved by parliament in 1757. The second, more radical, stage of enclosure (*enskijte*) began in the southern parts of Sweden in 1803, moving to the northern parts in 1827, and the majority of land was enclosed by the 1870s (Dahl, 1961; Gadd, 2000). State-employed land surveyors took part in both storskijte and enskijte, helping "to make a correct map of the village, lead the negotiations, and mark the new field boundaries." (Dahl, 1961, 60). Although initiated later in Sweden (1757), the pace of reform was not significantly different to England, where parliamentary enclosure began in 1604 and the majority of land was enclosed by the end of the eighteenth century (Wordie, 1983)

1832 reforms that aimed to create a unified framework based on private individual property rights and liberalized labour markets (Kopsidis and Wolf 2012; Pfister and Kopsidis 2015; Kopsidas et al 2017). However, this work has not always accounted for the prior existence of cadasters in West Prussia in 1832 and used measures of agricultural productivity that are themselves endogenous to cadastral reform.[21] While not challenging demand-side explanations, our findings suggest that, in the Prussian case, as elsewhere, certain institutional reforms do matter.

4.2 State Capacity and Taxation

Most historical and some modern cadasters are fiscal, i.e. established to assist tax collection by providing the state with information on the value of assets and who is liable. Thus it seems straightforward to suggest that cadastral reform should increase revenue from property and direct taxes. However, cadasters may also have more diffuse effects beyond direct taxes, boosting the state's information capacity – its ability to collect information on and interface with private citizens and businesses.[22] Thus we also test the effects of cadasters on indirect taxes and tax revenue as a whole.

We use data from the *Government Revenue Dataset* (UNU-WIDER, 2021) on different aggregations of tax revenue in a panel of up to 115 countries over 1980-2015. We use four different measures: *property* taxes; *direct* taxes (including property, income and profit taxes); *indirect* (consumption) taxes (such as VAT and trade taxes) and the *total tax ratio* (total tax revenues excluding social contributions and resource taxes), all expressed as a share of GDP (see Table C1 for data description).

Column (1) in Table 7 reports the estimate for property taxes, which is positively signed, but not significant. Property taxes only make up a very small percentage of all taxes (the mean level is 0.78 percent of GDP). Direct taxes in column (2) make up a more substantial part of all tax revenues (8.58 percent of GDP on average). The estimate for direct taxes is positive but also measured with imprecision.

[21] The measure of agricultural productivity used (in Kopsidis and Wolf 2012), the Grundsteuerreinerdrag (GRE – income from agrarian use of land), was calculated using the cadastral surveys.

[22] It is important to acknowledge that cadastral reforms may themselves augment, or be part of broader efforts to improve informational capacity that might positively influence two of our dependent variables in this paper – tax revenues and GDP itself. This is a further reason for caution in the interpretation of our results.

Table 7: Effect of *Cadaster* on Tax Revenue, 1980-2015 and 1960-2015

	Dependent variable:							
	Property taxes	**Direct taxes**	**Indirect taxes**		**Tax ratio**		**Tax ratio (ANRR sample)**	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$Cadaster(t)$	0.026	0.043	0.773***	0.971**	1.126***	1.054***	0.907*	1.285**
	(0.046)	(0.179)	(0.260)	(0.398)	(0.370)	(0.377)	(0.502)	(0.609)
Mean	0.78	8.58	10.79	10.79	19.28	19.28	18.13	18.13
y_t, lags	1	1	1	4	1	4	1	4
M_t, lags	1	1	1	4	1	4	1	4
Period			1980-2015				1960-2015	
N	2,361	2,454	2,640	2,265	2,499	2,145	4,429	4,084
Countries	108	108	115	111	106	105	115	115

Note: This table reports the within estimates of *Cadaster* on measures of tax revenue as a share of GDP. Results in columns (1-6) are based on (Bolt et al., 2018) sample and the UNU-WIDER (2021)'s data for 1980-2015 and results in columns (7-8) are on Acemoglu et al. (2019)'s (ANRR) sample and data for 1960-2015. Unbalanced panel of 105-115 countries. Information about the number of lags of the dependent variable and in y_{it} in each specification is included. Each specification includes (unreported) country and year fixed effects. Standard errors are in parentheses, clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1.

In columns (3)-(4), our outcome variable is indirect taxation with a mean value of 10.79 (percent of GDP). *Cadaster* enters statistically significant, and positively signed when we include either one and four lags of the dependent variable and GDP levels, and a typical cadastral reform of 0.3 increases the level of indirect taxation by 0.23-0.29 percentage points as a share of GDP. This effect is most likely what is driving the overall result in columns (5)-(6), showing that the total tax ratio also increases as a result of cadastral reforms. At the mean (19.28), and using the coefficient in column (6), a typical cadastral reform would lead to an increase in total taxes by 1.6 percent (0.3*1.054/19.28).

To check the robustness of this result, we use tax ratio as a share of GDP from Acemoglu et al. (2019). This data is available for a longer period, 1960-2010, and the number of country-year observations nearly doubles from around two to four thousands. The magnitude of the estimates in columns (7)-(8) are similar to those in columns (5)-(6).

These results seem to be at odds with the intuition that cadastral reforms increase state capacity to tax fixed assets. However, it is important to be cautious at drawing too firm a conclusion about this given the limited data availability on property taxes. The main take-away from this analysis is that recent cadastral reforms since 1960 have had a small but immediate and lasting effect on indirect tax revenues.

Why might this be the case? A first interpretation, linked to arguments about the behavioural effects of formalization of property rights, is that cadastral reforms may cause an immediate increase in effective household wealth, which boosts consumption and, consequently, revenues from indirect taxation of goods and services. A second interpretation, rooted in the cadasters-as-state-capacity perspective, sees cadastral reforms as bringing the informal sector into the bureaucratic reach of the state. This may particularly matter for the collection of taxes, such as VAT, which is affected by the size of the informal economy. Cadastral reforms, which seem to increase the efficiency of property registration, may also affect attitudes that matter for tax compliance, such as interpersonal trust (Di Tella et al., 2007) and trust in the state (De Mel et al., 2013). The fact that the association is strongest in Europe, where informality is less of an issue, lends additional support to the first interpretation.

The effect of cadasters on indirect taxes aligns with an argument for cadasters affecting growth through this channel. Cross-country research on taxation has shown that economic growth appears to increase with the shares of indirect (consumption) and property taxes within countries and decrease with direct taxes (Acosta-Ormaechea & Yoo, 2012; Arnold et al., 2011). These findings have in turn caused international institutions such as the IMF and OECD to recommend that countries shift from perceived harmful direct taxes on labor and capital to a greater degree of indirect taxation (Baiardi et al., 2019).

4.3 Investment Demand

Both households and governments should benefit from the improved information about property rights that public cadasters imply. Cadastral reform should increase investment demand through what is known as the *de Soto effect* (Besley et al., 2012): as formalization is likely to improve access to collateral, it increases credit availability. Also public infrastructure investments such as roads and railroads should be facilitated by the clear assignment of rights in land and land demarcation.

Data on investment levels as a share of GDP are available from around 1960 from the World Bank (World Bank, 2021). The equation that we estimate is equivalent to equation (4), but the impact of an institutional reform on investment is likely to take some time to materialize through its effect on investment demand, credit supply, and government spending on public investments. Figure C2 of the Appendix shows the β-parameter estimates for *Cadaster* from estimating equation (4) when we sequentially include three lead values and six lagged values.[23] The results show that the impact of *Cadaster* is not only positive, as expected, but also increases over time. Already two years before a cadastral reform, the estimate is positive at 0.73 but not significant, possibly indicating a weak anticipation effect. The estimate peaks after 5 years at 1.11 and is significant at 5-percent level, after which it falls. A full cadastral reform is thus expected to increase the investment rate from the mean level of 23 to 24.11, five years after the reform.

In Table C8 in the Appendix, we further distinguish between capital formation in the private and the non-private sector. The number of countries with available data is unfortunately greatly reduced from more than five thousand to around two thousand country-year observations, and the coefficients are not significant in any of the decompositions. Taking these results together, it appears that investment is not as strong an intermediate mechanism between cadasters and economic growth as transaction costs or state capacity. This suggests that what matters is not the *de Soto effect*, but rather the Coasean importance of clarity of property rights.[24]

5 Discussion

The general tendency throughout the tables has been that our *Cadaster* indicator displays a positive and significant coefficient during the last century when controlling for country and year fixed effects, pre-trends in GDP per capita, as well as for other potentially relevant factors such as democracy and population density. The impact is mainly driven by a strong relationship within Europe and Africa. Cadastral reforms are strongly associated with lower transaction

[23] Columns (1)-(4) of Table C6 in the Appendix presents the details of some of these estimations.

[24] Investment demand and credit supply are, in turn, likely to have an impact on the equilibrium real interest rate. In Table C7 of the Appendix, we exploit recently published historical time series on the real interest rate (i.e. the nominal interest rate net of inflation, in percent) from three European countries with long time series, collected by Schmelzing (2020): United Kingdom (1314-2012), France (1387-2012) and the Netherlands (1400-2012). In our analysis, we make use of both the annual data as well as the filtered series (the latter might be seen as a proxy for a more stable real natural interest rate, as in Jorda et al. (2020)). For the United Kingdom and the Netherlands, the estimates are positive and significant and the estimates for UK are particularly high. Given the very few countries with available historical data, it is however not possible to draw any general conclusions about these effects.

costs in terms of days of waiting for registration and with increases in indirect taxation. There are some indications that investment as a share of GDP acts as an intermediate channel, but this is not mainly driven by private investment (*de Soto effect*). We found that reforms in 19th century Germany were associated with an initial increase in farm density per unit of farmland. The coefficient for *Cadaster* from the within panel regressions more often becomes significant the closer we get to our own time period. There might of course be several reasons for this result. One possibility is that cadastral reforms will only be effectively growth-enhancing if they happen in an environment with competitive and trustworthy financial intermediaries and administrative institutions that are efficient and free of corruption (Arruñada, 2017; Besley et al., 2012).

Taking the results in their totality, we interpret them as being consistent with our hypothesis that cadastral reforms should have a positive association with economic growth. However, despite our efforts, we recognize that in long-run cross-country research it is generally nearly impossible to completely rule out reverse causality between institutional variables and indicators for economic development or the presence of important omitted variables. Acemoglu et al. (2019), as well as others, attempt to solve the endogeneity problem by employing GMM and HHK estimators, in addition to including instrumental variables (IV) for changes in institutions. Unfortunately, it is often very difficult to find an IV that credibly satisfies the exclusion restriction of having a causal effect on the independent, endogenous variable, but not on the dependent variable.

We cannot completely rule out that there exists some omitted variable that influences both cadastral institutions and GDP levels and hence threaten claims of a causal identification. In our analysis we have controlled for a number of such variables, such as levels of democracy, but not all. For example, our country examples suggest that cadastral reforms often happened within a cluster of institutional reforms, which makes it hard to interpret the impact of cadaster in isolation. We do not claim to have found a watertight strategy in this paper, nor that other confounding effects do not exist. We do, however, believe we have demonstrated a very strong correlation between cadastral institutional reforms and economic growth at the cross-country level over a long term, which is well in line with the main trend in existing micro-level evidence. We hope that our *Cadaster* variable will prove useful in future work on the relationship between property rights reforms and economic development.

6 Conclusion

In line with the literature on the importance of property rights institutions for economic growth (Acemoglu et al., 2005; North, 1990) and research on the effects of improved land property rights and cadastral reforms (Besley, 1995; Galiani & Schargrodsky, 2010; Libecap & Lueck, 2011a; Yoo & Steckel, 2016), we hypothesized that cadastral reforms should have a positive impact on economic growth since they provide states with the information they need to tax and make ownership visible to economic agents in ways that reduce transaction cost, underpin security of tenure and enable functioning land and credit markets at national scale. Using our newly developed measure of state-administered cadastral records for the last 1000 years, *Cadaster*, we found that controlling for pre-trends in GDP, country and year fixed effects in a large panel of countries, there is a statistically significant and sizeable positive effect of the introduction of cadastral institutions on GDP per capita. Although the limitations of cross-country observational data prevent us from being able to definitively establish this as a causal relationship, the magnitude of the effects and robustness of these results are suggestive and important. Our analysis of intermediate mechanisms suggest that transaction costs are lowered and that indirect taxation increases in response to cadastral reforms.

We hope that by initially establishing broad correlations between cadasters and economic growth and examining several intermediate mechanisms, our study and data can help to inform future research. As better historical data becomes available on economic activity, our cadastral data's long time-series can be more fully exploited, increasing the historical validity of arguments about the centrality of both property rights institutions and taxation to growth. One challenge with our paper is the high level of abstraction in our theory, which is necessary for it to travel across the many historical and geographic contexts our measure covers. With further refinements to the coding of our data to capture important aspects of the institutional design of cadaster – e.g. whether fiscal or legal, under unified or fragmented ministerial control, managed centrally or sub-nationally – and the identification of potential cases for micro-level analysis using the rich contextual information in the codebook of our data, the exact mechanisms of influence could be more directly explored. Our initial data collection effort has focused on establishing broad patterns over long time periods for the majority of countries. We hope that with this starting point we, and other researchers, will be able to deepen our understanding of the relationship between state-administered cadastral institutions and development.

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A Constructing the *Cadaster* Indicator: Coding Principles and Examples

In this Appendix we discuss our main coding decisions and provide some examples. An online 100+ pages long online Appendix *Dates and Sources* provides a comprehensive description of all cadaster-related events for every country in the sample with supporting references.

A.1 What is *Cadaster?*

We define cadaster as a state (public) record containing a description of a land and/or property asset and a party (individuals or organizations) that holds interests – rights, restrictions and responsibilities (RRR) – over it. In other words, a cadaster is a state-administered record, which contains two interlinked elements containing three pieces of information: a record related to the spatial unit (*what*) and a record related to a party (*who*) that holds RRRs (*which*) over it.

States adopted cadaster records at different times and for different reasons. Most historical cadasters (Kain & Baigent, 1992) and some contemporary ones (Erba, 2008) were adopted for fiscal purposes. The primary aim of fiscal cadaster is to assist tax administration to collect taxes, and, although they contain information on property rights associated with a land parcel, fiscal cadaster are concerned with assessing the value of land and identifying the person responsible for paying taxes and not with a detailed description of a bundle of rights/obligations (Kent, 1988; Lai et al., 2015). On the other hand, the primary aim of legal cadasters is to describe RRRs by people/organizations over a land parcel. Both types of cadasters identify a spatial unit and a party that holds rights over it, but, compared to legal cadasters, fiscal cadasters, are less concerned with the accuracy of boundary and the RRRs description. "Legal cadasters differ from fiscal cadaster not so much in terms of the kind of information they contain, but in the accuracy of the locational, boundary, and ownership data which they include." (Kent, 1988, 106). As such both types of cadasters provide some essential delimitation of property rights. Today most countries aspire to multipurpose cadasters, which together with fiscal and land property rights management functions, include land use and planning functions (Williamson et al., 2010).

Our coding does not distinguish between fiscal and legal cadasters, which would make the basis for a rich and insightful empirical analysis. There are considerable difficulties to cleanly date the transition from one to another even in well-established cadasters. For example, Erik Stubkjaerb, a distinguished cadaster scholar, upon whose expertise we drew considerably in the course of data collection, was able to pinpoint the transition of cadaster from fiscal to legal only down to a century in his native Denmark (authors' notes of a meeting).

A.2 Private cadasters

Private cadasters preceded and often ran in parallel to state-administered ones. Evidence of private surveying of the estates of large landlords in Europe can be traced back to the Middle Ages, when the main use of land description, sketches and maps was to adjudicate property disputes (for an overview of mapping in Europe, see Kain (2007); for England's manorial surveying in the Middle Ages see Jones (1979)). Private surveying became a permanent feature of European history in the early 16 century. For example, in England, the first printed surveying manual by John Fitzerbert, known as "The Boke of Surveying and Improvements", was published already in 1523 (Fitzherbert, 1931), suggesting that surveying was in high demand and on the threshold of professionalization (McRae, 1996, p. 172). Surveying of land was undertaken in connection with probate inventories – inventories of an individual's possessions at the time of death – and since at least the 1520s some of these inventories had been accompanied by maps (Smith, 1995). Property surveying was also undertaken in conjunction with enclosure, and maps were drawn privately (not least because enclosure was illegal: between 1489 and 1624, eleven Acts Acts forbidding enclosure were passed by Parliament (Blomley, 2007, p. 4) to assist the division of the common land (Blomley, 2007; McRae, 1993). Further, "The dissolution of the monasteries [in 1536-1542 – the authors] also had far-reaching consequences for the production and use of maps. As land from the former religious houses came on to the market and passed into lay hands, new owners and newcomers to the land market – those who benefited from the economic and social changes of the later decades of the century – needed to know the extent and boundaries of their possessions." ((Bendall, 1995, p. 34), see also Bendall (1993)). The subsequent development of the market economy affected the role of the surveyor, whose main responsibility by the mid-to-the-end of the 16th century was to provide advice to owners of manors on how to manage their properties more effectively (and even 'profitable' as Valentine Leigh, a surveyor, claims in the preface of his 1577 book "The Moste Profitable and Commendable Science, of Surueying of Landes, Tenementes, and Hereditamentes" (Leigh, 1577)), based on information on the size and legal status of landholdings. As McRae (1996) aregued, surveying had tapped into an increased demand by landlords "to know one's own".

Private cadasters could be found in other parts of Europe. For example, Sweden's project of state mapped cadaster, which began in 1628, was informed by Gustav II Adolf's experience in the Thirty Years' War, which brought him in contact with German landlords who practiced "cadastral mapping for the purposes of boundary delimitation and taxation... albeit rather sporadically" (Baigent, 1990, p. 64).

Private surveying of land was limited neither to Europe, nor to medieval or early modern period. In the 19th century, most large landholders in many Latin American countries used privately commissioned cadastral services to manage their estates, and the first step towards state-administered cadaster was often associated with the state incorporating these private cadasters as state records. For example, in Argentina the state cadastral project began in 1824 with the state collecting cadastral maps from landowners, the accuracy of which then being verified by the central Topographical Commission (Gautreau & Garavaglia, 2012) . Compared to state cadasters, private cadasters contain information about property rights only in relation to a specific landed estate, even if a large one, and this information is not publicly available. Produced mostly for boundary dispute resolution and as an aid in estate management and planning, private cadaster do not serve the same role of making the property rights visible to economic agents in ways that enable the functioning of land/property and credit markets at large scale.

A.3 Was there a state-administered cadaster?

To document the existence of a cadaster we went through several thousands sources in different languages: mostly English, but also Spanish, Russian, French and Portuguese. The sources could be classified into three groups. First, there are documents prepared by professional surveyors and land administration specialists. Invaluable information was obtained from the *Cadastral Template* project – a collection of standardised descriptions of the historical cadasters and the main features of contemporary land registration systems in 60 countries around the globe, carried out by the International Federation of Land Surveyors (*FIG*). Indispensable information was found in documents of the Permanent Committee on Cadastre in the European Union (*PCC*) and its Latin American counterpart - the Comité Permanente sobre el Catastro en Iberoamérica (*CPCI*).

Second, there are reports by governments and international organisations – African Development Bank, Development Bank of Latin America, USIAD, World Bank and others – involved in cadaster reforms and land registration projects.

Third, there is specialised multidisciplinary scientific literature, examining cadasters in past and present, including peer-reviewed publications, working papers and PhD theses. Kain &

Baigent (1992) is a very important source on historical cadastral reforms in Europe, while Erba (2008) and Bosch Llombart (2007) offered detailed historical account of cadastral reforms and a description of the current state of land registration systems in the countries of Latin and Central America.

A.4 Narrative or mapped cadaster?

Description of land parcels comes in two forms: narrative and cartographic (mapped). Narrative cadasters identify land assets using simple instrumentation (e.g. rod, Gunter's chain) and techniques (e.g. human observation of geographical landmarks, ranging) and describe them in sentences of a language: *"Beginning at a white oak in the fork of four mile run called the long branch and running No 88' Wt three hundred thirty eight poles to the Line of Capt. Pearson, then with the line of Pearson No 34' Et One hundred Eighty eight poles to a Gum.* (Libecap & Lueck, 2011a, p. 426-427). Early cadasters, for example, the Chinese cadaster before 1143, Ottoman *tahrir defterleri*, Russian *pistovyi knigi* or Swedish *jordeböcker* were narrative. However, narrative cadasters are not an artefact of the past: for example, Brazil's rural cadaster remained narrative until the turn of the 21st century and Afghanistan's only cadastral project of 1966-78 was carried out without mapping.

Cartographic cadasters identify land parcels based on observations and measurements of a more systematic character, compared to those of narrative cadasters. For example, cartographic cadasters do not depend on the features of local geography (such as the white oak in the example above) in the identification of land parcels. Furthermore, cartographic cadasters present the information about a land holding's location, dimensions and features diagrammatically, i.e. in a drawing or sketch, accompanied by legend (see Figure 1).

Cartographic cadasters are a superior property rights assigning institution than narrative cadasters for three reasons. First, cartographic cadasters identify the subject of property rights more accurately as they rely on more sophisticated instrumentation (e.g. theodolite, lidar) and techniques (e.g. triangulation) of land surveying than narrative cadasters. Second, mapped cadasters present the information in a more transparent way, allowing cadastral information to be understood by economic agents without local knowledge, thereby facilitating not only land-related market transactions, but also other trade. Third, a system of mapped cadasters often led to a standard where land was divided into rectangular plots of similar size, whereas traditional land-holdings were often divided into smaller and irregular polygons which made their value less easy to assess in the local land markets. Figure A1 contrasts an example of a rectangular land demarcation in contemporary Ohio, United States, with a non-rectangular demarcation west of Abuja in contemporary Nigeria. The scale is the same in both maps. In 2015, the *Cadaster* score for United States as a whole was 1 and the score for Nigeria was 0.03.

Figure A1: Satellite image of land demarcation in Ohio (left panel) and in Federal Capital Territory, Nigeria (right panel), 2020

Note: Images are from Google Maps. Same scale is applied to both maps.

To quantify the difference between mapped and narrative cadasters we begin with Lai et al. (2015)'s interpretation of Coase that "when the cost of enforcement is high, less than fully defined, but sufficiently clear, property rights can still be efficient" (p. 274). It implies that a shift from 'no cadaster' to 'a cadaster' is more important than an improvement in the quality of descriptions of the *what*, *who* and *which*. Consequently, a shift from using maps rather than verbal description is less important than a shift from 'no cadaster' to 'a cadaster' even with a narrative description of the land/real estate assets. Furthermore, the specialized literature treats cartographic cadasters as an evolutionary development of narrative cadasters (Kain & Baigent, 1992), which also implies that the distance between narrative and cartographic cadasters is smaller than the distance between no cadaster and a narrative cadaster. This suggests that the weight of the narrative cadasters should be larger than .5.

In other to quantify this weight with higher precision, we draw on Libecap & Lueck (2011a), who found, in the context of a natural experiment in Ohio, that areas where land assets were identified through narrative cadasters had fewer mortgages, conveyances and lower land value, compared to areas with cartographic, rectangular cadasters. They point out that the precision of descriptions of land assets and, therefore, the strength of property rights in narrative cadasters is lower, compared to cartographic ones, as "outsiders have little knowledge of local conditions and topography to determine the exact location and nature of parcels to be traded on" (Libecap & Lueck, 2011b, 260). In their most conservative estimation, Libecap & Lueck (2011b) found that switching from a narrative to cartographic cadaster yields an increase in land value per acre of over 40 percent (Libecap & Lueck, 2011b, 287-288). To exemplify, a land parcel valued at $12 under narrative cadaster would be valued at least $16,8 under cartographic cadaster. In other words, the value of the same land parcel under narrative cadaster is 0.71 of its value under the cartographic cadaster. Because the Libecap & Lueck (2011b)'s estimate of 0.71 is "most conservative", we code country/years with narrative cadaster as 0.75 and country/years with cartographic cadaster as 1.

A.5 How much of the country's territory was covered by the cadaster?

In the third step of the data construction, we specify the coverage of state-administered cadastral recording across a country's territory. As a general rule, we calculate the *implementation weight* as a percentage of the current territory under cadaster. Table A1 illustrates an example of coding for Ireland.

Table A1: Coding example: Ireland

Year	Cadaster event	Cadaster type	Cadaster coverage, % of the territory	Score
1586-1655	1	1	2,75	0,0275
1656-1847	1	1	66	0,66
1848-2015	1	1	100	1

Coding information:

1586-1655: (1, 1, .0275). The first survey of the Munster plantation (land confiscated by the English Crown, following the Desmond rebellions); mapped; covering approximately 500,000 acres (Andrews 2007: 1680; Andrews 1985; MacCarthy-Morrogh 1983), which constitutes 2,75 percent of the current territory.

1656:1847: (1, 1, .66). The Down Survey, mapped, estimated at 12 million acres, or two-thirds of the island of Ireland (House of Commons 1824: 32).

1848-2015: (1,1,1). The Griffith's Valuation (carried out between 1848 and 1864 to determine liability to pay the Poor rate), accompanied by Ordnance Survey maps, full coverage (National Library of Ireland, n.d.).

This coding principle applies to all historical (pre-1900) cadasters in Europe, settler colonies (the US, Canada, Australia and New Zealand) and colonial surveys (e.g. British India and Burma or Japanese Korea).

Although scholarly consensus exists on most of the incidents of cadaster reform, evidence with regard to some land reforms remains inconclusive. For example, the literature remains inconclusive regarding the implementation of the Ottoman Land Code of 1858 (Quataert, 1997; Ruedy, 1971; Tute, 1929, 858-859), with most researchers agreeing that it was not fully implemented. In the absence of any data on implementation, we assign a 50 percent implementation weight. Similarly, a 50 percent weight is applied to the case of pre-colonial Korea (Yoo & Steckel, 2016). This can be revised as new evidence becomes available.

For post-1900 cadasters we have to account for different dynamics of cadastrification of urban and rural land, impelled by rapid urbanization in the 20th century. While cadaster reforms took place in many countries of the world since the 1900s (see Figure ??), in many countries the implementation varied substantially between rural and urban lands. The case of Colombia typifies the situation in Latin America, where urban cadasters progressed at a much high speed than rural cadasters. In Colombia, since the early 1930s 66 percent of all urban parcels have been properly surveyed and registered, but only 16 percent of rural parcels (Barajas, 2016). On the other hand, a recent program of certification of rural land in Ethiopia resulted in 60 percent of rural parcels being covered by a narrative cadaster, compared to 30 percent of urban parcels being mapped and registered (Shibeshi, 2011). To calculate z^3_{it}, we multiply the share of cadastrified rural/urban parcels by the share of rural/urban population and sum the products.[25] To illustrate, after independence in 1990, Namibia's effort to maintain the cadaster inherited from the times under the South African's mandate resulted in 20 percent of rural parcels and 60 percent of urban parcels being properly registered and surveyed (Owolabi, 2004). We multiply 20 and 60 by the shares of rural and urban population (64.3 and 35.7 percent correspondingly) and sum the terms to obtain $z^3_{Namibia} = 0.343$ for the 1990-2004 period.

While parcel-based measure of the coverage – share of the properly surveyed and registered parcels in the total number of parcels – is the the most accurate measure, it is not available for all country/years. For most of the remaining country/years we have data on the implementation of rural cadasters, but the data comes in a number of different forms. First, it comes as the share of regularized agricultural land over the total agricultural land. For example, between 1949 and 1972 Ecuador regularized 1,45 million hectares out of 16,2 million hectares of land suitable for agriculture, livestock exploitation and forestry. Second, data on the coverage of rural cadasters comes as the share of the total land, which needs to be normalized through the

[25] z^3_{it}= (share of rural surveyed and registered parcels x share of rural population) + (share of urban surveyed and registered parcels x share of urban population)).

share of agricultural land in the total land to calculate the coverage. For example, post-Soviet Azerbaijan successfully utilized cadasters of the Soviet-era collective farms (i.e. agricultural land) to regularize privatized land, amounting to 20 percent of the territory in 2004. By expressing this 20 percent as a share of agricultural land (58 percent in 2003), we calculate rural component of $z^3_{Azerbaijan2004}$ as 0.34.

Finally, for a number of country/years the available coverage data is even less specific. First, the coverage is reported in the number of owners having legal documents to land. For example, in 1975 Algeria began a program of cadastrification of the territory suitable for agriculture — north of the 34th parallel (World Bank 1992, 7). However, in 1992 only "5 percent of private rural and urban owners have legal evidence of their property rights" (World Bank 1992, 6; see also World Bank 1992, 9; World Bank 2001, 2). In such cases we assume the share of *owners* to be equivalent to the share of properly surveyed and registered parcels in the *total number of parcels*. In the case of Algeria $z^3_{Algeria1992} = 0.05$.

Second, reporting standards of cadastral projects are often inconsistent. For example, the units of measurement ("parcels", "municipal areas", "hectares") in the World Bank's Land Administration Project I in Guatemala vary not only between the appraisal and completion reports, but also between different regions of the country (World Bank 2010: 70). In such cases we anchor the score component z^3_{it} in the total of the country's territory. In the case of Guatemala, based on the World Bank's reports, we conclude that by 2007 cadaster was fully functional in five departments of Guatemala, yeilding $z^3_{Guatemala2007} = 0.47$.

B Cadastral reforms in 19th century Prussia

B.1 Background

The first cadaster in Germany was introduced in Brandenburg-Prussia in 1680 and reforms were independently rolled out in different parts of the German lands during the 17-18th centuries. In 1808, western parts of Kingdom of Prussia were occupied by Napoleon's forces and mapped cadastral surveying was then introduced in the Rhineland, Westphalia and Bavaria, amounting to about a third of the current country territory. After the peace treaty in 1815, the Napoleonic cadaster was maintained in the Rhineland and Westphalia provinces of the Kingdom of Prussia.

After emancipating the peasantry (1807) and passing the Edict of Regulation on landownership (1811), enabling peasants without hereditary rights to become freeholders for the first time, the Kingdom of Prussia introduced a uniform legal framework based on private property and liberalized labour markets, overlaying historically different institutional conditions (Kopsidis & Wolf, 2012). However, the Prussian agricultural system remained divided between the west and east provinces (see (Byres, 1997, 43-160)) for a authoritative account of the differences). East of the Elbe, agricultural production since the 16th century was under a seigneurial system (the peasantry providing labour service) on large farms owned by the junker class. Despite peasants gaining personal freedom in the early 19th century, most of them gained no land as "The Junkers took over and enclosed... the land of both poor and rich peasants – the land they worked and common land." (Byres, 2009, 50). West of the Elbe, the agrarian system was based on the peasantry paying dues rather than labour on smaller sized farms, and the emancipation resulted in the most peasants with previously non-heritable or cancelable tenancy redeeming the land by ceding between 1/3 and 1/2 of the land to their landlord.

The years 1861-65 were a period of tax and land reform. The tax reform required a revision of the cadaster in the western provinces of the Kingdom of Prussia and the creation of the first cadaster in the eastern provinces. It was used to produce high precision estimates of agricultural productivity liable for taxation and was based on the income from agrarian use of land less costs of farming. From 1867, all of contemporary German had a full mapped cadaster.

Thus, within 19th century Germany there is a distinction between the East (historically larger average farm size, little land gains by peasants from emancipation and late cadaster) and the West (historically smaller average farm size, land gains by most of the peasantry from emancipation and earlier cadaster). We propose that farm density per unit of farmland is a key outcome variable for analyzing the consequences of cadastral reform. As discussed above, cadastral reform in the western provinces enabled the majority of small-scale peasants to become formal owners of land for the first time in a setting with historically smaller size of landholdings. Following a Coasian logic, one may conjecture that the first phase cadastral reforms facilitated an increase in the number of registered farms though lower land conveyancing and other transaction costs. Cadasters may also improve transferability of property rights with assets flowing to those who can use them most productively, hence leading to lower farm density in the longer term. However, both processes may be of the smaller magnitude in the east given that there were already fairly large farms before the cadastral reform and that emancipation did not turn the peasantry into landholders en mass as it did in the west.

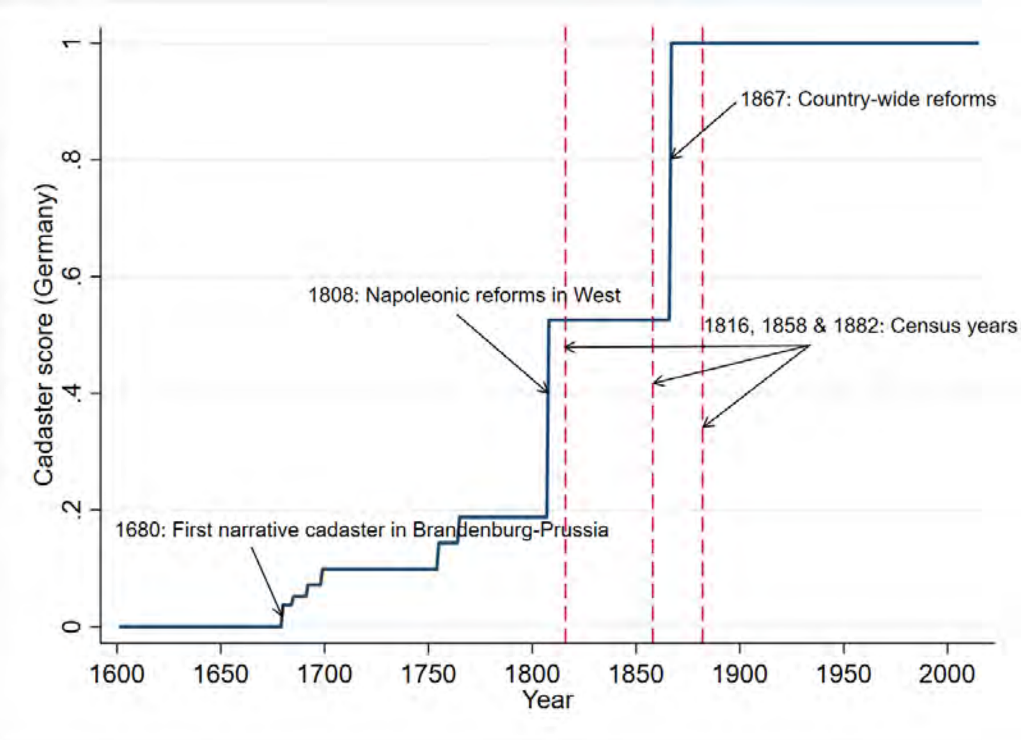
B.2 Data

To test these conjectures, we use data from the Ifo Prussian Economic History Database (iPEHD, 2021), which contains digitized information from the Prussian censuses of the 19th century at the county level. We study the impact of cadastral reforms on the size distribution of farms in 1816, 1858 and 1882. The first date, 1816, was right after the end of the Napoleonic Wars when the western provinces Rhineland and Westphalia maintained the cadastral reforms that had been imposed by the French in 1808. The second date, 1858, was nine years before the full cadastral country-wide cadastral reform in 1867. The last census date, 1882, is fifteen years after the country-wide reform (see Figure B1).

One the basis of the three waves of census data, we construct a variable Log Farm density, capturing the number of farms per sq km among 1816 counties. There are a number of aspects of this data that needs comment. The first concerns the counties themselves, which are the basic unit of analysis. Counties in 1816 were later split up into smaller counties, which complicates intertemporal comparisons. Our solution is the following: If a county i is splits up into, say, five counties, we aggregate the number of farms for all of these new five counties in 1858 and 1882 into the "origin" county of 1816 and maintain the early larger county as the primary unit of analysis throughout the period.The figure shows the .

The variable capturing the development of farm density among 1816 counties is created in the following way: During the three census years, we sum information about the total number of farms across different size categories to obtain the total number of farms. We then divide this number by the area of total farmland. As the denominator for each of the three measures of farm density, we use total country farmland, measured in sq, in 1882. There are two reasons for this choice: First, the iPEHD (2021) data base does not provide information on the total area

Figure B1: The development of the *Cadaster* indicator within contemporary Germany, 1600-2015

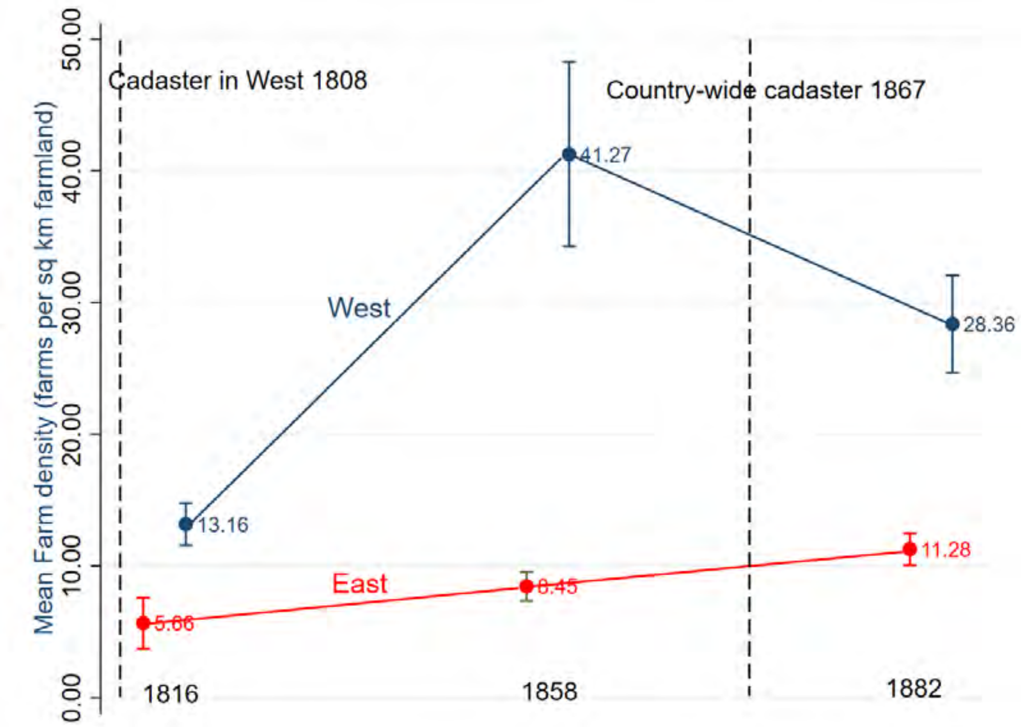


Note: The figure shows the development of our Cadaster index for Germany during 1600-2015. Key reform events in 1808 and 1867 are shown in graph, as well as census years 1816, 1858, and 1882.

under cultivation in 1816 or 1858. Second, we do not have any reason to believe that extensive colonization of new farmland occurred during the 19th century. Hence, total farmland area in 1882 should be a decent proxy for the whole period. Third, even if some new farmland was settled in some regions, for comparison it would still be preferable to relate to a fixed total farmland area. The resulting three meaures thus show farm density per sq km of farmland in 1882 among aggregated counties defined by their 1816 borders. We also create two dummies for cadastral reform: A dummy for provinces that experienced a full cadastral reform already in 1808 (Rhine Province and Westphalia) and another dummy for provinces that experienced a transition to a full cadaster in 1867 (all the rest of (eastern) Prussia). Provinces that became part of the unified Prussia at a later stage such as Bavaria, Schleswig-Holstein and Hanover, are not included in the analysis.

Figure B2 below shows the development of the Farm density measure over time and across the two main categories of provinces in terms of cadastral reform: The early western cadaster regions of 1808 and the later eastern regions that had a full cadaster only in 1867. As discussed above, the figure shows that the mean farm density was higher among the western provinces already in 1816 (13.16 farms per sq km of 1882 farmland versus 5.66 farms in the east). After the end of the war and the persistence of full cadasters in the west, farm density increased very rapidly to 41.3 farms per sq km in the west, whereas density grew more modestly in the east to 8.4 farms per sq km. The evidence for land consolidation is weaker, with density declining in the West before the country-wide cadastral reform, and a statistically insignificant negative coefficient in the regressions.

Figure B2: Mean levels of *Farm density* per sq km in western and eastern regions of Kingdom of Prussia, 1816-1882



Note: The figure shows mean farm density per sq km of 1882 farmland area in 1816, 1858 and 1882 among counties in western (Rhine and Westphalia, dark blue lines) and eastern provinces (all other provinces that were part of Kingdom of Prussia in 1816, red lines). Later acquired provinces such as Schleswig-Holstein, Hanover and Bavaria are not included in the comparison. Vertical lines display confidence intervals of means and mean levels are indicated in the graph.

C Additional Tables and Figures

In this section, we present additional tables and figures for the analysis in the paper.

Comments on Table C7:

In columns (2)-(3) of Table C7, we include binary dummies for all country-years when *Cadaster*=1 (*Full Cadaster*) and all country-years when *Cadaster*=0 (*No Cadaster*). The first dummy is identical to the one used in the earlier analysis of semi-parametric treatment effects ($c_{it} = 1$) except that *Full Cadaster* includes all observations whereas the semi-parametric analysis only included the period leading up to a transition to a full cadaster.

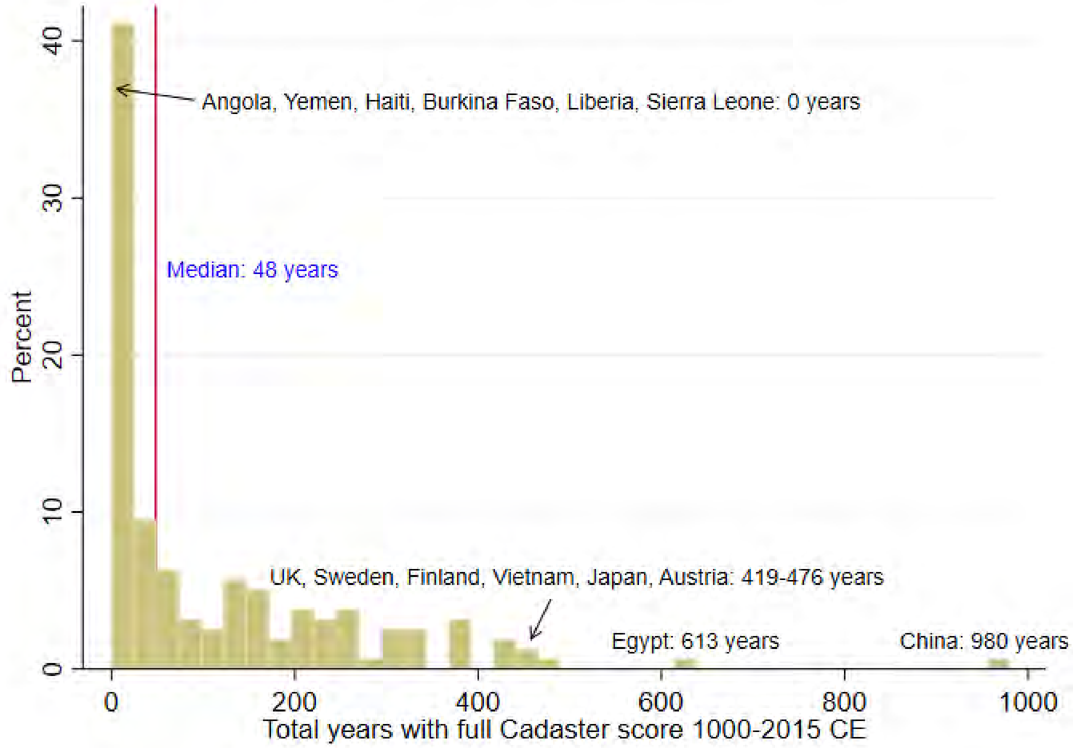
In column (1), we include the baseline within-estimate for *Cadaster* from Table 3, column (6) for comparison. The marginal impact of a transition to a full cadaster, 1.29, in column (2) is lower than in column (1) and measured with less precision. The estimate in column (3) indicates that a country that moves from some cadastral institution to having none at all, is expected to reduce its level of GDP per capita that by 0.86 percent.

In column (4), we include one of the most commonly used variables for measuring the level of democracy – *Polity2* from the *Polity IV* dataset (Marshall et al., 2019) – ranging between +10 for full democracies to -10 for full autocracies. Although we have already explored "horse races" between democracy and cadastral institutions in Tables 1-2, one might still be concerned that cadastral reforms could potentially pick up the signal from democratization. In column (4) we see that the estimate for *Cadaster* does not change substantially and remains significant whereas *Polity2* has no discernible effect. A similarly imprecisely measured estimate is observed in column (5) for an alternative measure of (liberal) democracy from the V-Dem Institute (Coppedge et al., 2019).

Could it be the case that cadastral reforms are related to population density so that reforms become necessary when population pressures are very high? There is indeed a positive correlation between population density and the strength of cadastral institutions in our sample. In column (6), log population density has a negative and significant impact on log GDP per capita but the coefficient for *Cadaster* remains of similar magnitude as before and is significant.

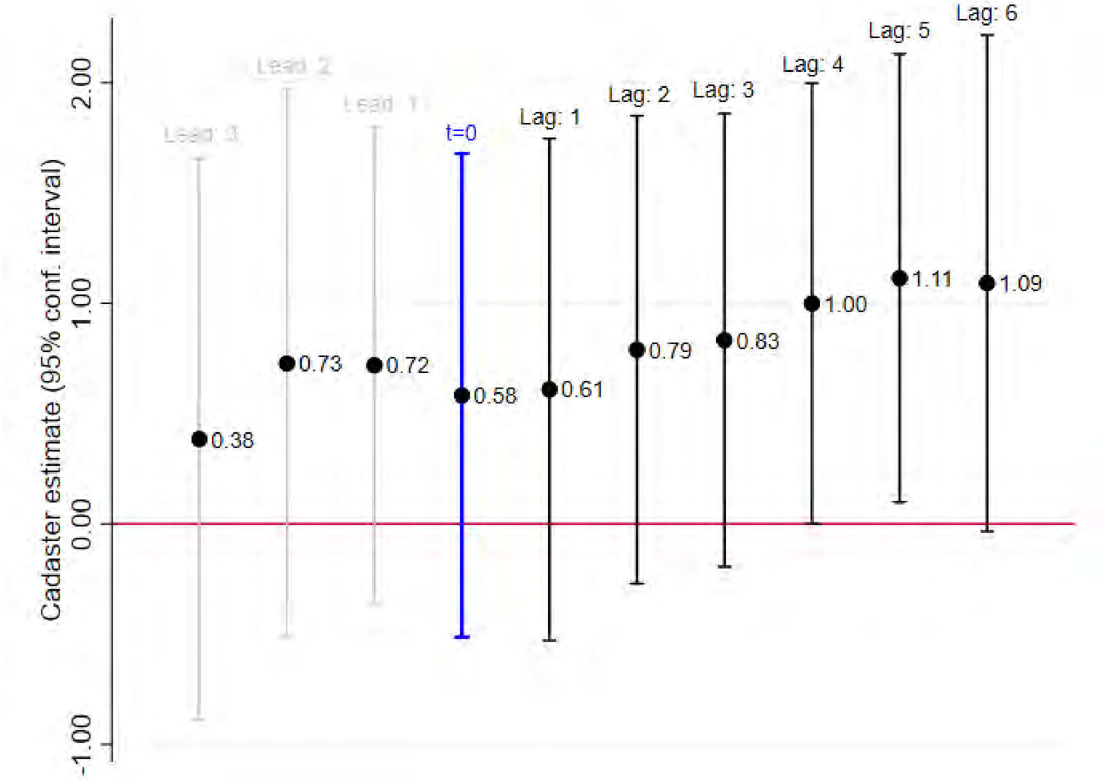
One might be concerned that cadastral reforms just happen to be rolled out at the same time as other reforms that reflect an increasing state capacity that is the true driver of increases in income per capita. One candidate for such a scenario is a country's health infrastructure. In column (7) we include infant mortality per 1000 live births as a proxy for public health investment. Interestingly, the estimate for *Cadaster* rises when infant mortality is included. As expected, years with a high infant mortality rate are associated with lower levels of GDP per capita within countries. In column (8) the estimates for all three control variables – regime type, population density and health infrastructure – are statistically significant, and the coefficient for *Cadaster* is 2.67 and its positive impact is measured with precision.

Figure C1: Distribution of aggregate *Cadaster* scores across 158 countries



Note: This figure plots a distribution of the aggregate number of years with a full cadaster (*Cadaster*=1) for 158 countries.

Figure C2: Effect of lead and lag levels of *Cadaster* on the *Investment share of GDP*, 1960-2015



Note: The graph presents the within beta coefficients of the effect of lead and lag levels of *Cadaster* on *Investment share of GDP* 1960-2015 in line with equation (5). *Cadaster*'s coefficients are multiplied by 100. 95 percent confidence intervals are shown as capped vertical lines. Three light grey lines to the left show pre-reform effects, blue line shows simultaneous effect and the six black lines to the right show lagged effects. Four lags of log GDP per capita are included in all displayed specifications. Standard errors are clustered on country level. In each specification, we control for a full set of country and year fixed effects. Unbalanced panel including up to 150 countries.

Table C1: Variable definitions

	Variable definitions
Cadaster variables:	
Cadaster	See section 1-2
Full Cadaster	Dummy variable =1 when Cadaster=1; 0 otherwise
Outcome variables:	
Log GDP per capita I	Log of real GDP per capita with constant prices x100 (Acemoglu et al, 2019)
Growth rate of GDP per capita I	Growth rate of real GDP per capita with constant prices in year x (($\ln y_t$-$\ln y_{t-1}$)x100) (Acemoglu et al, 2019)
Log GDP per capita II	Log of real GDP per capita with constant prices (RGDPNApc) in year 2011 (Bolt et al, 2018)
Growth rate of GDP per capita II	Growth rate of real GDP per capita with constant prices (RGDPNApc) in year 2011 ($\ln y_t$-$\ln y_{t-1}$) (Bolt et al, 2018)
Procedures	Estimated typical number of procedures required for registering a business (number)
Time	Estimated typical typical time cost for registering a business (days)
Cost	Estimated typical cost as a share of property value for registering a business (%)
Property taxes	Total tax revenues on property, including real estate, net wealth, inheritance and gift taxes, as a share of GDP (%)
Direct taxes	Total direct taxes, including taxes on income, profits, and property, excluding social tions and resource taxes, as a share of GDP (%)
Indirect taxes	Total indirect taxes, including taxes on goods, services, international trade and transactions, and other taxes, as a share of GDP (%)
Tax ratio	Total tax revenues, excluding social tions and resource taxes, as a share of GDP (%)
Log Tax ratio	Total tax revenues as a share of GDP (%)
Investment ratio	Gross capital formation as a share of GDP (%)
Private Investment ratio	Gross fixed capital formation in the private sector as a share of GDP (%)
Non-Private Investment ratio	Gross fixed capital formation in the non-private sector (Inv. ratio - Priv. inv. ratio) as a share of GDP (%)
Real interest rate	Real interest rate (nominal interest rate - inflation) (%)
Control variables:	
Democracy	Dummy variable=1 when Freedom House codes country as "free" or "partially free" and when Polity IV> 0; 0 otherwise
Polity2	Standard measure of democracy from Polity IV data set. Full democracy=10, full autocracy=-10
Liberal democracy	Measure of liberal democracy from V-DEM data set
Log Population density	Log of total population in country divided by total area in sq km.
Infant Mortality	Mortality among infants per 1,000 live births

Note: This table provides definitions of variables included in the empirical panel study.

Table C2: Data sources and coverage

	Source	Temporal coverage	Countries	Mean
Cadaster variables:				
Cadaster	This study	1000-2015	159	.120
Full Cadaster	This study	1000-2015	159	.063
Outcome variables:				
Log GDP per capita I	Acemoglu (2019)	1960-2010	175	748.3
Growth rate of GDP per capita I	Acemoglu (2019)	1960-2010	175	1.83
Log GDP per capita II	Bolt et al (2018)	1252-2015	150	8.23
Growth rate of GDP per capita II	Bolt et al (2018)	1252-2015	150	1.37
Procedures (number)	World Bank (2022)	2005-2015	149	6.07
Time (days)	World Bank (2022)	2005-2015	149	64.04
Cost (% of prop. value)	World Bank (2022)	2005-2015	149	6.14
Property taxes	UNU-WIDER (2021)	1980-2015	108	.751
Direct taxes	UNU-WIDER (2021)	1980-2015	108	8.52
Indirect taxes	UNU-WIDER (2021)	1980-2015	115	10.38
Tax ratio	UNU-WIDER (2021)	1980-2015	106	18.20
Log Tax ratio	Acemoglu et al (2019)	1960-2010	115	-184.6
Investment ratio	WDI (2021)	1960-2015	148	22.99
Private Investment ratio	WDI (2021)	1960-2015	92	16.43
Non-Private Investment ratio	WDI (2021)	1960-2015	91	7.67
Real interest rate	Schmelzing (2021)	1314-2012	8	5.94
Control variables:				
Democracy	Acemoglu et al (2019)	1960-2010	175	.513
Polity2	Marshall et al (2019)	1950-2015	153	1.04
Liberal democracy	Coppedge et al (2019)	1950-2015	145	.343
Log Population density	WDI (2018)	1961-2015	147	3.78
Infant Mortality	WDI (2018)	1960-2015	147	55.6

Note: This table provides sources, maximum temporal coverage, maximum number of countries in a given year and means (all country-year observations) for all variables included in the empirical panel study.

Table C3: Data availability and cumulative cadastral reforms over time

	Data availability and cadastral reforms over time				
	1500	1800	1900	1950	2000
Cadaster (#countries)	159	159	159	159	159
Cadastral improvements (#reforms $\geq$ 0.1)	20	56	114	144	191
Cadastral reversals (#reforms $\leq$ -0.1)	4	27	28	37	55
GDP per capita II (#countries)	11	19	44	125	153

Note: This table shows the number of countries with available data at different points in time for *Cadaster* and *GDP per capita II* over our study period. *Cadastral reforms* shows the cumulative number of reform episodes at different points in time where the absolute changes in *Cadaster* exceed 0.1. For instance, 38 cadastral reversals in 1950 implies that there had been 38 cadastral reversals in history, i.e. changes in a country's cadaster variable < -0.1, up until 1950. The total number of such reforms over 1000-2015 is 261.

Table C4: *Cadaster* and Quality of Land Administration Indicators: pairwise correlations

Indicator	**Corr. coeff.**	**N**
Quality of Land Administration (aggregate)	0.7521***	142
Reliability of infrastructure	0.7128***	142
Geographic coverage	0.4564***	142
Transparency of information	0.7079***	142
Land dispute resolution	0.4703***	142
Equal access to property rights	0.3225***	142

*** indicates significance at 1-percent level

Note: Table shows the Pearson correlation coefficients between *Cadaster* for 2015 and components of the World bank's *Quality of Land Administration Index* for earliest available year 2016. The first row shows the correlation with the aggregate index whereas the last five shows correlations with subcomponents of the aggregate index. Levels of significance of the correlation as well as number of country observations (142) are indicated in the table.

Table C5: Effect of *Cadaster* on the growth rate of real GDP per capita (Maddison data, 1252-2015)

	Dependent variable: Growth rate of real GDP per capita							
	1252-2015		**1900-2015**		**1950-2015**			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Cadaster	0.601	0.644	1.571**	1.531**	1.879**	1.779**	1.663*	1.594*
	(0.469)	(0.474)	(0.723)	(0.756)	(0.830)	(0.838)	(0.849)	(0.879)
Δy_{t-1}	0.060**	0.062**	0.152***	0.154***	0.214***	0.203***	0.207***	0.224***
	(0.028)	(0.029)	(0.027)	(0.027)	(0.038)	(0.035)	(0.038)	(0.040)
Δy_{t-2}		0.002		0.032		0.071**	0.068**	0.055*
		(0.022)		(0.022)		(0.030)	(0.031)	(0.030)
Δy_{t-3}		0.015		0.005			0.033*	0.040**
		(0.017)		(0.019)			(0.018)	(0.017)
Δy_{t-4}		-0.000		-0.002			-0.009	-0.017
		(0.011)		(0.013)			(0.013)	(0.013)
N	16,251	15,741	11,089	10,705	8,896	8,793	8,583	8,155
Countries	150	150	150	150	150	150	150	150

Note: Table presents the within estimates of the effect of *Cadaster* on the growth rate of real *GDP per capita* for three different time intervals. *Cadaster*'s coefficients are multiplied by 100. Estimates of all included lags of the growth rate of GDP per capita are included in all columns except in column (8), where 8 lags of y_t are included. Standard errors, clustered on country level, in parentheses. In each specification, we control for a full set of country and year fixed effects. Unbalanced panel including 150 countries. *** p<0.01, ** p<0.05, * p<0.1

Table C6: Propensity for cadastral reforms (Maddison data, 1900-2015)

	Dependent variable:					
	Full Cadaster=1			$c_{it} = 1$		
	(1)	(2)	(3)	(4)	(5)	(6)
y_{t-1}	0.007***	0.011***	0.014***	0.002***	-0.001	0.002
	(0.000)	(0.002)	(0.002)	(0.001)	(0.011)	(0.015)
y_{t-2}		-0.002	-0.001		-0.010	-0.022
		(0.003)	(0.003)		(0.017)	(0.026)
y_{t-3}		0.001	0.001		0.020	0.032
		(0.003)	(0.003)		(0.019)	(0.030)
y_{t-4}		-0.003	-0.005**		-0.007	-0.008
		(0.002)	(0.002)		(0.013)	(0.022)
Year FE			✓			✓
N	11,781	11,301	11,301	6,694	6,414	1,070

Note: The table reports marginal effects from a probit of the dummy variables *Full Cadaster* in columns (1)-(3) and transition to full cadaster c_{it} in columns (4-6) on lags of log GDP per capita and Year FE. *** p<0.01, ** p<0.05, * p<0.1

Table C7: Robustness analysis: Effect of *Cadaster* on GDP per capita, controlling for time-varying confounders (Maddison data, 1950-2015)

	Dependent variable: Log GDP per capita 1950-2015							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Cadaster	2.012**			2.422**	2.485**	2.631***	3.251***	2.674***
	(0.789)			(0.942)	(1.068)	(0.864)	(1.076)	(0.753)
Full Cadaster		1.291*						
		(0.690)						
No Cadaster			-0.862*					
			(0.486)					
Polity2				0.001				-0.041*
				(0.018)				(0.022)
Liberal dem.					0.470			
					(0.708)			
Log Pop. dens.						-1.808***		-2.823***
						(0.593)		(0.679)
Infant mortality							-0.012**	-0.029***
							(0.005)	(0.006)
Country FE	✓	✓	✓	✓	✓	✓	✓	✓
Year FE	✓	✓	✓	✓	✓	✓	✓	✓
yt, lags	4	4	4	4	4	4	4	4
Observations	8,689	9,069	9,069	7,561	7,479	6,795	6,696	6,494
Countries	150	153	153	148	145	147	147	147

Note: The table reports the within estimates of the effect of different lags of *Cadaster* and time-varying control variables on log GDP per capita. *Cadaster*'s coefficients are multiplied by 100. Unbalanced panel of 145-153 countries. All specifications contain four lags of Log GDP per capita (not reported) and country and year fixed effects. Standard errors are in parentheses, clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1

Table C8: Effect of *Cadaster* on gross, private, and non-private investment

	Dependent variable:							
	Gross investment ratio				**Private investment**		**Non-private investment**	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Cadaster(t)	0.861	0.582			-1.199		0.842	
	(0.588)	(0.555)			(1.956)		(0.880)	
Cadaster(t-1)			0.609			-1.443		0.485
			(0.576)			(1.833)		(0.767)
Cadaster(t-2)				0.789				
				(0.536)				
y_t, lags	1	4	4	4	4	4	4	4
I_t, lags	1	4	4	4	4	4	4	4
N	5,672	5,210	5,217	5,223	2,003	2,008	1,960	1,965
Countries	148	148	148	148	92	92	91	91

Note: Table presents the within estimates of *Cadaster* on gross, private and non-private investment as a share of GDP. *Cadaster*'s coefficients are multiplied by 100. Estimates of all included lags of the growth rate of GDP per capita are included in all columns except in column (8), where 8 lags of y_t are included. Standard errors, clustered on country level, in parentheses. In each specification, we control for a full set of country and year fixed effects. Unbalanced panel including of 91-148 countries. *** p<0.01, ** p<0.05, * p<0.1

Table C9: Effect of *Cadaster* on the real interest rate in three countries, all available years

	Dependent variable:					
	Annual real interest rate			**Average real interest rate**		
	UK	**France**	**Netherlands**	**UK**	**France**	**Netherlands**
	(1)	(2)	(3)	(4)	(5)	(6)
Cadaster	17.724***	-1.907	7.106***	3.084***	-.552	1.527***
	(3.578)	(1.672)	(1.882)	(.999)	(.425)	(.514)
	[4.402]	n.a.	n.a.	[1.235]	n.a.	n.a.
r_{t-l}, lags 1-4	✓	✓	✓	✓	✓	✓
Δy_{t-l}, lags 1-4	✓	✓	✓	✓	✓	✓
trend	✓	✓	✓	✓	✓	✓
N	695	588	599	691	584	595
R^2	.56	.30	.14	.96	.90	.76

Note: This table reports the OLS estimates of *Cadaster* on the real interest rate (in percent) in the UK, France and the Netherlands. The dependent variable: the annual real interest rate (columns (1)-(3)) and the average real interest rate (a five-year moving average) in columns (4)-(6). All specifications include four lags of the dependent variable, the growth rate of GDP per capita and a linear time trend (not reported). Robust standard errors in ()-parentheses and Newey-West standard errors (four lags) in [ ]-parentheses, where available. *** p<0.01, ** p<0.05, * p<0.1 based on t-values from robust standard errors.