Land Property Rights, Cadasters and Economic Growth:

A Cross-Country Panel 1000-2015 CE

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Abstract

Since the transition to agricultural production, property rights to land have been a key institution for economic development. Clearly defined land rights provide economic agents with increased access to credit, secure returns on investment, free up resources used to defend one's land rights, and facilitate land market transactions. Formalized land records also strengthen governments' capacity to tax land-owners. Despite a large body of extant micro-level empirical studies, macro-level research on the evolution of formal rights to land, and their 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 (i.e. centralized land records) 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, supporting theoretical conjectures that states with more formalized property rights to land should experience higher levels of economic growth.

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1 Introduction

Well-defined property rights are central to current understanding of the causes of economic development (Acemoglu et al., 2005; Coase, 1960; North, 1990). For a number of reasons, it is believed that property rights to land play a particularly important part in the process of economic development. Before the Industrial Revolution, land was one of the two key factors of production (labour being the other) and also constituted the most important source of wealth in Western Europe and the USA up into the early twentieth century (Piketty, 2014). Land remains a crucial production asset in many developing countries today, both as an important element in the global food supply chain and a source of livelihood for many households as they harvest its fruit, graze animals or use the water it carries. Further, due to "its immobility and virtual indestructibility"(Gardner & Rausser, 2001, p. 299), land lends itself to use as collateral, thereby intensifying monetization of the economy and economic exchange. However, both historically and today, land rights tend, to a large extent, to be poorly defined. De Soto (2016a,b) estimates that about 4.7 billion of the global population lack formal property rights to land.

A large body of theoretical literature argues that clearly defined land rights provide economic agents with secure returns on investment, reduce the resources needed to defend one's land, facilitate land market transactions and allocation of scarce resources to the most efficient user, and increase access to credit. Despite these strong theoretical reasons, no clear-cut conclusion emerges from empirical studies that have attempted to test the link between well-defined property rights in land and economic growth. Existing literature is dominated by research on micro-level and lacks a cross-country perspective. Furthermore, most studies have examined short-term effects and the long-term impact of the evolution of land rights remain overlooked.

This paper attempts to address these gaps by empirically examining the relationship between formalized property rights to land and economic growth in a large panel of countries over more than 1000 years. Our analysis is based on a novel data set, tracing historical variation in formal land rights within contemporary country borders.[1] We document the emergence

[1] We recognize that whereas some modern countries such as Sweden or Japan have had relatively fixed borders across the centuries, many other country borders have changed numerous times over the years. We argue that our choice to stick to countries within contemporary borders as the unit of analysis, makes our study more comparable to several other studies that follow the same approach, for instance Borcan et al. (2018)'s study

and evolution of state-administered *cadasters* (i.e. centralized land records of ownership by individuals as well as by communal groups or legal entities) for 159 countries between 1000 CE and 2015, ranging from China's introduction of comprehensive cadastral records already in 1000, Sweden's reform of the 1530s and Vietnam's in the 1470s, to a whole range of countries like the Republic of Congo, Turkmenistan and North Korea that by 2015 had still not adopted any cadaster. We also observe reversals when existing cadastral institutions have been either purposefully abandoned (like in the Ottoman empire (c.1600) or Russia (c.1650)) or destroyed in conflict (like in Cambodia or Laos in the 1970s).

We then analyze the association between cadastral institutions and long-run economic growth in a cross-country panel stretching back to medieval times. An obvious concern in cross-country work on the causal linkages between institutions and economic development is endogeneity. Whereas institutional reforms often lead to economic growth, periods of stagnation might also initiate institutional reforms. Our strategy in this regard is to mimic the baseline specification of the well-known dynamic model in Acemoglu et al. (2019), where a binary indicator of democracy rather than cadastral institutions is leveraged against income levels and growth.[2] This empirical strategy allows us to focus on within-country variation while also controlling for pre-trends in GDP, year-specific general shocks, etc.

We find that 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 2.16 percentage point immediate increase in the level of GDP per capita. Such drastic cadastral reforms are however rarely observed in history. Considering instead a more typical partial reform (for instance, the launch of a cadaster covering part of the country's territory or a move from a narrative to a mapped cadaster), our estimates imply an instantaneous increase in GDP per capita of 0.65 percent. The estimates are generally measured with precision, economically meaningful and robust to the inclusion of alternative measures of GDP, lagged values of our cadaster variable, and potential confounders such as democracy and population density.

of the economic importance of the length of state history or most papers within the empirical cross-country growth literature.

[2]We acknowledge that in cross-country income levels or growth regressions, it is nearly impossible to fully account for the universe of potentially relevant omitted variables and we do not claim the associations that we have uncovered should necessarily be interpreted as strictly causal.

We then introduce our *Cadaster* indicator to the cross-country panel data from Acemoglu et al. (2019). Having replicated their main within-country analsysis regarding the impact of democracy on economic growth in 1960-2010, we show that our *Cadaster* index remains significant after the inclusion of both institutional variables, suggesting a separate channel of impact of cadasters on economic development from political rights. When we employ the same calculation of long-run effects as in Acemoglu et al. (2019), we find that a full reform is associated with an 53 percent increase in GDP levels in the long run, as compared to the 21 percent increase in GDP from the introduction of Acemoglu et al. (2019)'s indicator of democracy. In order to probe deeper into these dynamics, we conduct an in-depth event study of the four countries with the longest (predating 1500 CE) available time series for GDP per capita: the United Kingdom, France, Sweden, and the Netherlands. We find that cadastral reforms to be associated with increased growth rates of GDP per capita in all countries, but Sweden. The country case studies also illustrate that cadastral reforms like those in Napoleonic France in 1807 often occur simultaneously with other reforms, which makes it challenging to isolate a causal effect of an individual reform.[3]

We also examine two intermediate mechanisms from cadastral reforms to economic growth: the natural real interest rate and the investment ratio to GDP. 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 were 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. We further find that the investment ratio increased by about 1.1 percentage points five years after a full reform. This lagged impact of investment on GDP suggests that the observed immediate positive response from cadastral reforms on income levels must derive from some other source.

There is a very large literature on the economic impact of property rights institutions. Existing theoretical approaches, summarized by Besley & Ghatak (2010), suggest that well-defined property rights affect the level of economic prosperity enjoyed by individuals and countries through at least five distinctive pathways. First and foremost, because the lack of well-defined

[3]Although we have not studied this in detail, the same problem should apply to any analysis of causal impacts of democratic or other institutional reforms.

property rights is associated with insecurity – "a random probability of loss of future income due to conflicting challenges" (Gardner & Rausser, 2001, p. 296) – well-defined property rights assure economic agents that they will able to appropriate returns on their labour and capital, thereby incentivizing them to make productivity-enhancing, long-term investments. Second, property rights free up reduce resources used to protect property, thereby channelling resources into productive economic activity. Third, they facilitate market transactions: clear and enforceable property rights improve trade in assets and goods. Fourth, clear property rights and credible contract enforcement improve the efficiency of allocation of scarce resources, enabling them to flow to the most efficient owner. Fifth, they increase productivity by facilitating access to credit: where property rights are clear and easily enforceable credit organizations are more likely to accept an asset as collateral for a loan.

Similarly to generalized property rights, formal property rights in land increase investment incentives, decrease transaction costs associated with private protection of land assets and settle land disputes, increase the number of transactions in the land market and land value, as land assets reach those who value it the most, and improve the collateralizability of land assets (Besley, 1995; De Soto, 2000; Di Falco et al., 2020; Fenske, 2011; Galiani & Schargrodsky, 2010; Goldstein & Udry, 2008; Libecap & Lueck, 2011a; Yoo & Steckel, 2016).

It is broadly recognized that the state plays a pivotal role in creating well-defined property rights to land (Besley & Ghatak, 2010, p. 4526-4527). The introduction of national cadastral surveys have historically been part of a central government's broader ambition to impose *direct* rather than *indirect rule* over its territory (Scott, 1998) and to improve its *fiscal capacity* through fiscal centralization (Dincecco & Katz, 2016). The state has an advantage in describing land assets and ascribing rights associated with these assets in a unified manner, thereby reducing the information asymmetries between economic agents with and without local knowledge and triggering the mechanisms discussed above that link property rights with growth. For example, parts of the U.S. state of Ohio that fell under a state-mandated standardized system of describing land parcels (under the Land Ordinance of 1785), experienced more land market transactions, more mortgages and higher land value, than parts of Ohio where the boundaries of land parcels were defined locally and haphazardly with reference to features of local geography and man-made structures (Libecap & Lueck, 2011a).

Formalization of property rights over land may have both immediate and long-term effects. For example, following the introduction of land registration in 1905 in the Japanese colony of Taiwan, the number of land parcels changing hands through sales increased from 4,499 in 1905 to 51,137 in 1906 and the number of land parcels registered as collateral increased from 4,848 to 43,731 correspondingly (Yoo & Steckel, 2016, p. 639). Within two years after a similar reform by the Japanese colonial government in Korea in 1918, the amount of loans using land as collateral increased three-fold (Yoo & Steckel, 2016, p. 638). A natural experiment in the allocation of land titles among squatters in poor areas of Buenos Aires showed that households that moved from usufructuary land rights to full property rights promptly and substantially increased investments in their houses, the education of their children and experienced a modest improvement in access to mortgage (Galiani & Schargrodsky, 2010). Growth-enhancing effects of the formalization of property rights may persist over the long-run either because of the "advantage of an early start" (Bockstette et al., 2002) or due to the persistence of characteristics of the initial property defining institutions (for example, centralized vs decentralized) through path dependent channels as shown by Libecap & Lueck (2011a).

Despite strong theoretical arguments, the empirical literature does not uniformly support the proposition of the positive economic effects from the formalization of property rights in land. For instance, Besley et al. (2012) analyze the "de Soto" effect (associated with De Soto (2000)), which postulates that property rights strengthen incentives for using fixed assets as collateral, which in turn should lead to lower interest rates and greater profits. Using micro evidence from Sri Lanka, the authors show that the positive effects of formalization of property rights depend on whether the credit market is competitive or not. An influential survey of existing empirical research on the effects of land administration interventions reports strong, "albeit not uniform" (Deininger & Feder, 2009, p. 233), evidence that formalization of land property rights is associated with higher levels of investment and productivity, reduced need to defend land rights, increased rental market activity, but less so with access to credit. A further survey of this literature (Place, 2009) characterizes the empirical results as mixed. A more recent meta-analysis of 54 quantitative studies on the relationship between property rights in land and investment in Africa (Fenske, 2011) shows that the literature is dominated by micro-level studies (at the level of household level or below) and plagued with a number of methodological issues, such as small sample sizes, the use of binary investment measures and a variety of ambiguous proxies for formalization of property rights and security of tenure.

Existing empirical research clearly lacks a large comparative study on the macro level, and our paper closes this gap by introducing a data set that traces the evolution of formal property rights in land at the country level over 1000 years and by providing the first analysis of the growth effects of cadastral reforms.

The paper is organized as follows: section 2 presents the conceptual framework behind our empirical modelling; in section 3, we present the new data, including the coding that guided its construction and general trends in the *Cadaster* indicator; section 4 outlines our empirical strategy and reports the main results; in section 5 we carry out econometric analysis of two potential mechanisms linking cadastral reforms with economic growth. 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.

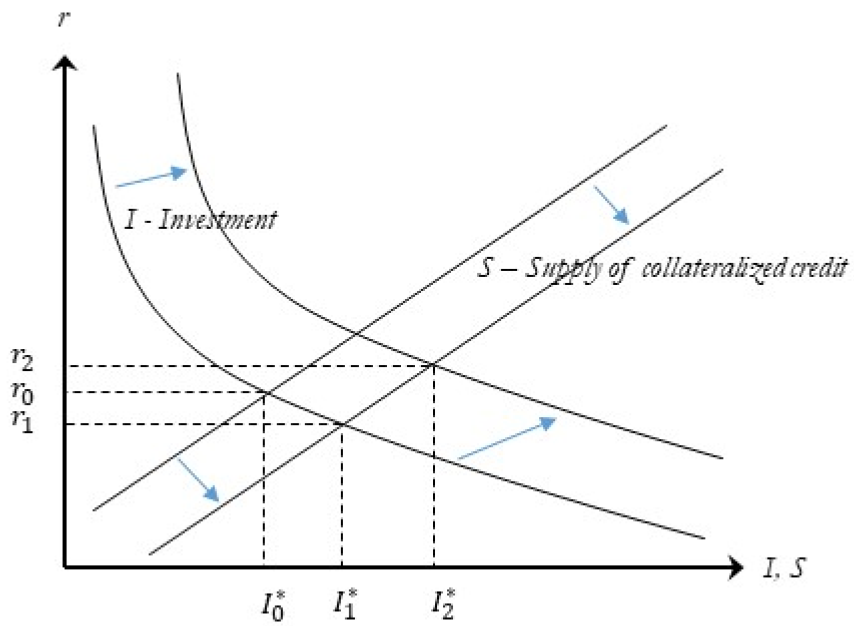
2 Conceptual Framework

This section briefly outlines the simple conceptual framework for our empirical analysis. Let us assume that there are two basic sectors: a large *rural* sector where land is a key input and an *urban* sector, specializing in trade and finance and that does not use land. The point of departure is a standard micro-founded macro model where rural investment demand is a negative function of the real interest rate $r = i - \pi$ where i is the nominal interest rate and π is the inflation rate. Our key agent is a representative rural *economic enterprise* that uses land as an input, such as an individual farm, a village council, a water mill, a religious institution or, after industrialization, a private manufacturing firm. What we call an *economic enterprise* might thus either be a single individual or a collective agent as in collectivist China. Enterprises hire capital K at a cost rK and trade off the marginal cost r of hiring an extra unit against the value marginal product of capital, i.e. its marginal contribution to total revenue. A lower real interest rate implies a higher optimal employment of capital and a higher level of investment demand, as shown in Figure 1. Since a higher level of investment gives rise to a higher level of capital, K is also associated with a higher level of aggregate production in the economy Y.

S is urban supply of credit to rural economic enterprises. The higher the real interest rate, the more willing are urban households are to forgo current consumption and instead save for the future. Savings are assumed to be channeled to credit market institutions that supply credit to rural enterprises. The higher the real interest rate, the higher the supply of credit that is channeled from urban households via credit market institutions to rural enterprises, as shown by the positive slope in Figure 1. In general, the slope and position of the S-curve reflects the quality of credit market institutions such that the curve will be placed further to the right in the case of well-functioning institutions.

In equilibrium, the crossing of the I- and S-curves determine the *real natural interest rate* as in standard macro models. In the initial situation, the curves cross at a real natural interest rate of r_0 and at a level of investment of I_0.

Figure 1: Investment demand and supply of credits as a function of the real interest rate



Note: The figure illustrates the real natural interest rate as an equilibrium between investment demand and supply of collateralized credit.

Let us now assume that a government cadastral reform — that records the boundaries of land parcels and rights and obligations associated with these parcels to land — is introduced in the country. As discussed above, such a reform will likely lead to a number of effects. One impact, which might be referred to as "de Soto effect" (Besley et al., 2012; De Soto, 2000), suggests that formalization of property rights to land implies that real estate assets can be used as collateral in credit applications. This provides a stronger security to lenders who become more willing to supply credit at a given real interest rate. If there are well-functioning credit market institutions, this results in a shift of the S-curve to the right. The level of investment increases to I_1 and the equilibrium real natural interest rate falls.

However, even at a given level of credit supply, a cadastral reform should also usually increase rural enterprises' willingness to invest. If the main rural economic enterprises are individual farms, a cadaster with officially recorded maps of individual property should give farmers a stronger confidence that their assets are not going to be confiscated or predated upon by the government or by private agents. In the case that such problems still arise, land owners whose assets and rights are recorded in cadastral records, have a higher probability of attaining a corrective decision in a court than land owners with informal property rights over their assets.[4] The increased willingness to invest is reflected in a shift of the I-curve to the right in Figure 1. Such a shift will lead to a further increased level of investment to $I_2 > I_1$. In the example in Figure 1, the net effect of the cadastral reform on the natural real interest rate is an increase to r_2. However, this will depend on whether the *de Soto effect* or the *investment effect* dominates. In either case, our conceptual framework suggests that investment should increase and hence the capital stock and levels of aggregate production Y.

Country-wide cadastral records are organized by a central government, often with the purpose of achieving a more efficient generation of tax revenues from land assets (Kain & Baigent, 1992; Scott, 1998). In this sense, the emergence of national systems of cadastral records is seen as part of a broader historical ambition of states to improve their fiscal capacity through centralization of state revenue (D'Arcy & Nistotskaya, 2018; Dincecco & Katz, 2016). If tax revenues increase as a result of the more detailed recording of private (and public) land, this should in turn lead to a greater provision of public goods such as roads, schools, and law enforcement.[5] Hence, cadastral reforms often have indirect macro-level effects beyond the investment and credit decisions at micro level.

The theoretical account above is necessarily stylized and highly simplified. In reality, the

[4]In the case where the relevant economic enterprise was a collective agent such as a farmer cooperative, laws regarding the rights of legal entities might prohibit efficient credit arrangements.

[5]It should be recognized that fiscal reforms are often carried out with the main objective of raising more revenue for military spending (Tilly, 1990a), which do not have a straightforward link to increasing prosperity.

imposition of cadastral systems also had significant direct and indirect costs. A direct cost was the resources required for state bureaucrats to survey land holdings, record land rights and continuously administer these records, especially in a pre-satellite and pre-computer era. Indirect costs of cadasters included the break-up of informal arrangements of land sharing and grazing on commons, evolved over centuries in accordance with local traditions and needs. In many places, cadastral and other reforms by a "seeing state" that aspired to measure, categorize, standardize, tax, and centrally plan its hinterland, were often met with local resistance (Scott, 1998). In order to evade taxation, people in Southeast Asia even migrated to frontier territories or to other countries (Scott, 2009). Such costs may have had a dampening effect on economic growth.

In the empirical section, we will study the reduced-form impact of cadastral reform on output per capita within countries across time. We will also analyze whether the mechanism runs through the real natural interest rate and aggregate investment levels.

3 The *Cadaster* Indicator

3.1 Constructing the Indicator

Empirical research on the effects of property rights in land has been hampered by the scarcity of suitable indicators. The micro-level research has predominantly relied on subjective indicators (Besley, 1995; Galiani & Schargrodsky, 2010), and the lack of data on property rights in land for countries has precluded comparative empirical research at the cross-country level.[6] We address this empirical gap in the multidisciplinary literature by developing a new measure of formal property rights in land based on the presence and characteristics of state-administered cadastral records.

Cadaster are records, containing, first, a description of land assets and, second, a description of interests – rights, restrictions and obligations – associated with the asset (Williamson & Enermark, 1996). One part of a cadastral record contains information that uniquely identifies land parcel – its location, dimensions and features – obtained through an external observation,

[6]For example, the International Property Rights Index (*IPRI*), a comprehensive measure of property rights around the world, does not feature rights in land as a component of the index.

usually a survey of land. 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 land asset.[7] These attributes make cadaster a suitable indicator of the formalization of property rights in land (Libecap & Lueck, 2011a; Yoo & Steckel, 2016). Furthermore, although the exact forms of land surveying and registration have changed due to technological development, their essence – demarcation of land assets and registration and codification of the rights (of individuals, communities, and legal entities) to perform certain actions with regard to these assets – has not. This attribute of cadaster has facilitated the creation of an indicator over a long period of time.

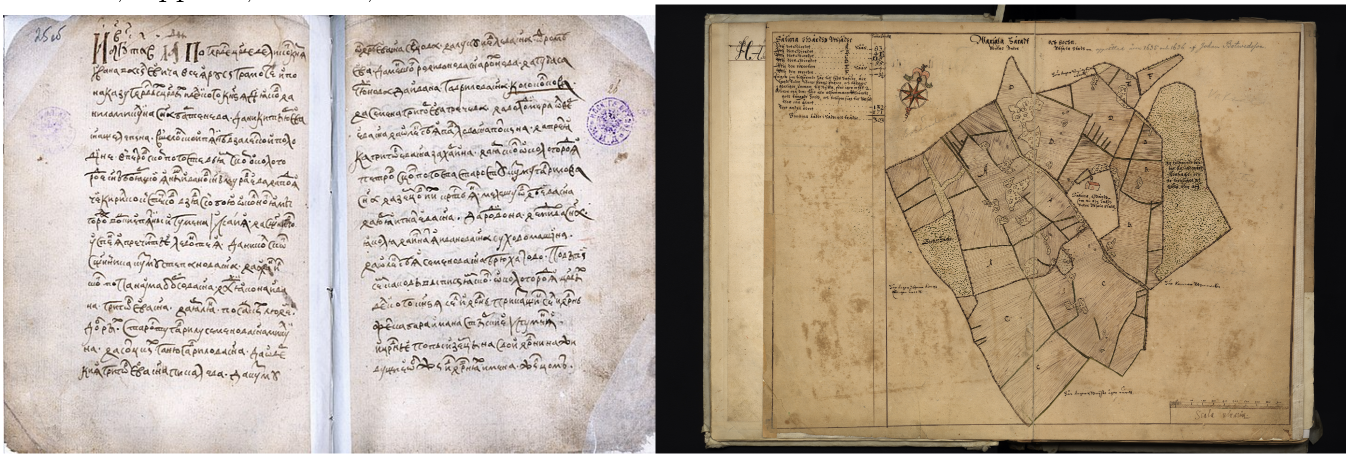
To create the *Cadaster* variable we assigned a score for each country/year, based on the answers to the following questions:

- "Was there a state-administered cadaster?" Country/year receives 1 point if "yes" and 0 points if "no", yielding score component 1 (z_{it}^1);
- "Was the cadaster narrative or cartographic?". Country/year receives 1 if cartographic and 0.75 if narrative, yielding score component 2 (z_{it}^2); Figure 2 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 percent of the territory, the score is 1.

These coding principals allow us to account for spatial and temporal change, including discontinuation of cadasters such as, for instance, in the Ottoman empire c. 1600 and Russia c. 1656 (Figure 3). These examples demonstrate that it cannot be assumed that once commenced cadaster institutions would 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.

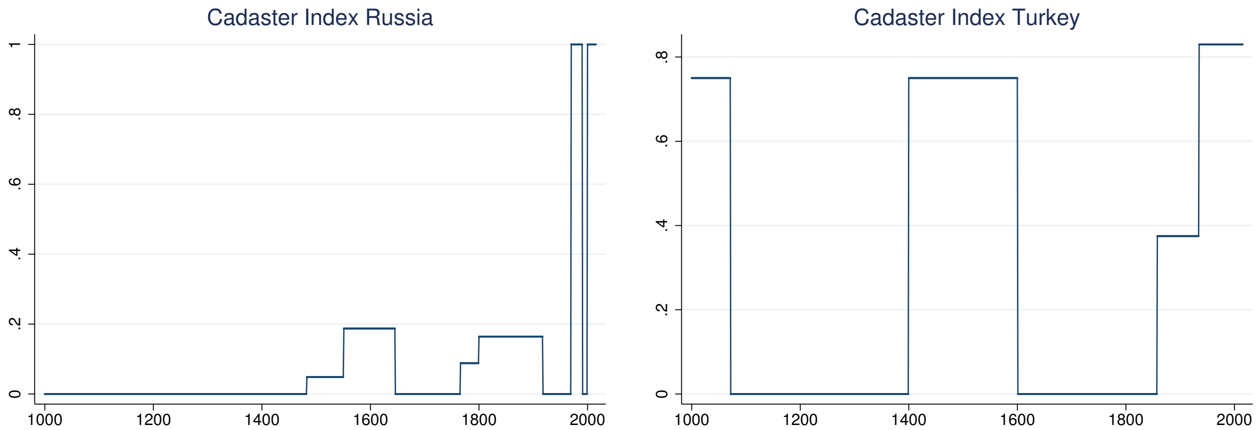
[7] Usually cadasters register the interests of individuals, but there are also examples of cadasters that are not predicated on individual property rights: such as the Soviet cadaster or cadasters of communal lands (such as under Kenya's 2016 Community Land Act).

Figure 2: 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*).

Figure 3: Evolution of *Cadaster* over time in Russia and Turkey



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

To this end, we used several thousand sources of information in different languages, the major of which are:

- The *Cadastral Template* project — a collection of standardised descriptions of the historical cadasters and contemporary land registration projects in 60 countries around the globe, carried out by the International Federation of Land Surveyors (*FIG*);
- Documents from the Permanent Committee on Cadastre in the European Union (*PCC*) and its Latin American counterpart - the Comité Permanente sobre el Catastro en Iberoamérica (*CPCI*);
- Specialised scientific literature, examining cadasters historically and/or presently, such

as Kain & Baigent (1992), which provides a thick description of historical cadastres for a large number of European states, or Erba (2008) and Bosch Llombart (2007) on the history and modern situation with cadasters in the countries of Latin and Central America;

- Reports by governments and international organisations, involved in land registration projects (e.g. African Development Bank, Development Bank of Latin America, USIAD, World Bank and others).

The coding principals went through a peer review by process (D'Arcy et al., 2019), receiving the approval of the professional association of land surveyors.

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

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

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

Appendix A describes in detail the principles of coding and illustrates the coding process. Accompanying this paper is also an online *Dates and Sources* Appendix — a 90+ page long document that provides a comprehensive description of the coding decisions with supporting references for all country/year observations.

3.2 A Brief Looks at the Data

The resulting data – *Cadaster* – is an annual unbalanced panel that comprises 159 modern-day countries from 1000 to 2015.[8] We observe a considerable range in *Cadaster* scores. China has the earliest history of comprehensive cadasters: a nationwide narrative cadastral survey took place in 2AD 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*)

[8]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.

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 until the Ottoman Land Code of 1858, which re-instituted cadaster, 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 4 depicts regional averages of *Cadaster* from 1000 to 2015, revealing a number of interesting patterns. First, there is no meaningful cadastral development 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, as the Ottoman empire begins its slow decline. 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.

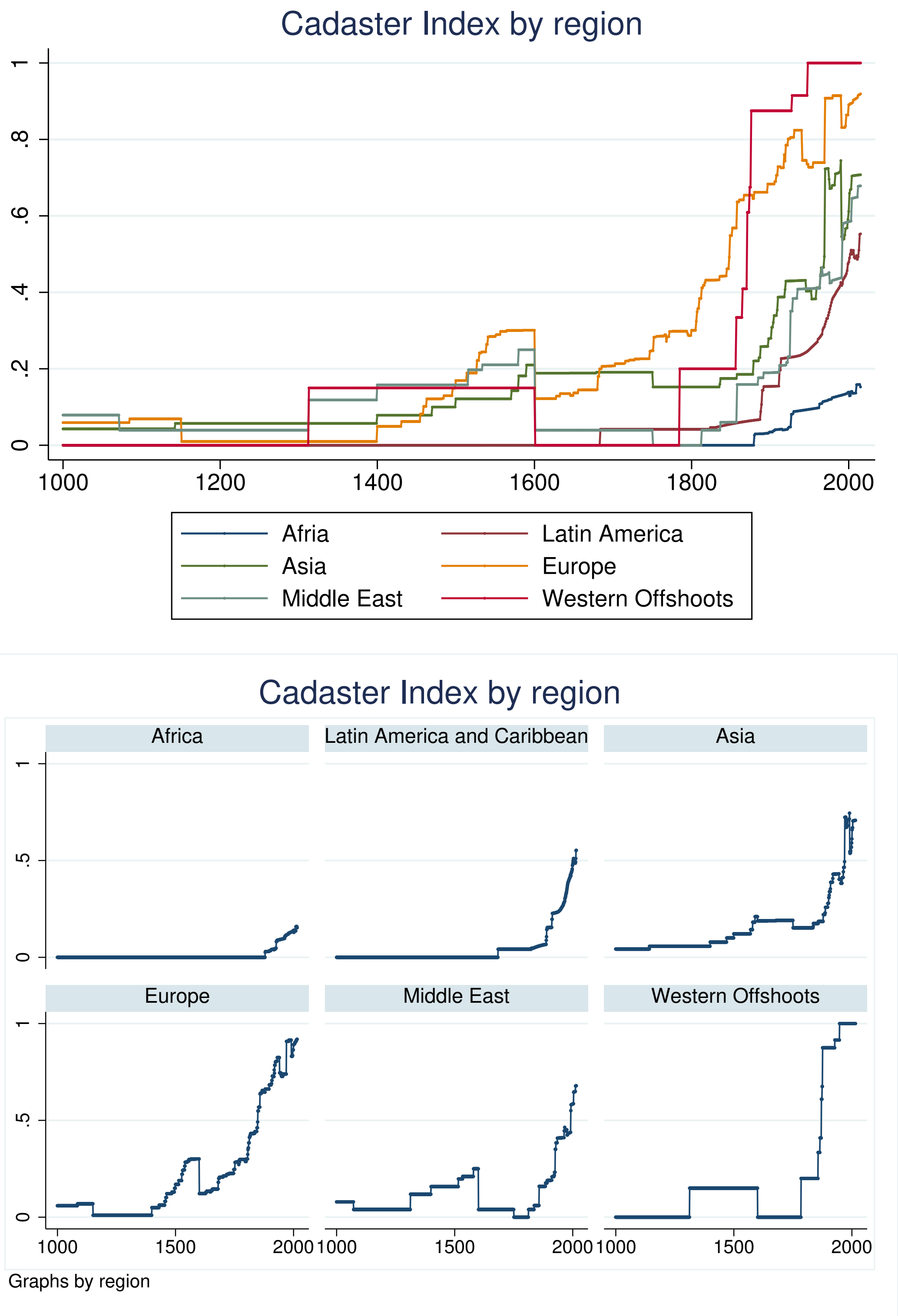
The summation of the *Cadaster* scores over all years for a country gives an indication of the country's accumulated experience of formal property rights to land.[9] Figure 5 shows a histogram of the aggregate score for each modern country over the 1000-2015 period. China and Egypt stand out in the right-hand side of the figure with 980 and 613 "total years" (i.e. the sum of *Cadaster* scores for all years) respectively. A group of countries, consisting of Sweden, Finland, Vietnam, Japan and Austria, have total years between 419-461 years, whereas the great majority of today's countries have a very short or no history of cadastral records, to the far left. The median *Cadaster* aggregate score for the whole period is 44.9 years.

4 Empirical analysis

In this section we analyze the quantitative relationship between the evolution of cadastral records and economic growth since 1000 CE. Our main hypothesis is that of a positive relationship between the existence of cadastral records and economic growth. In the introduction

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

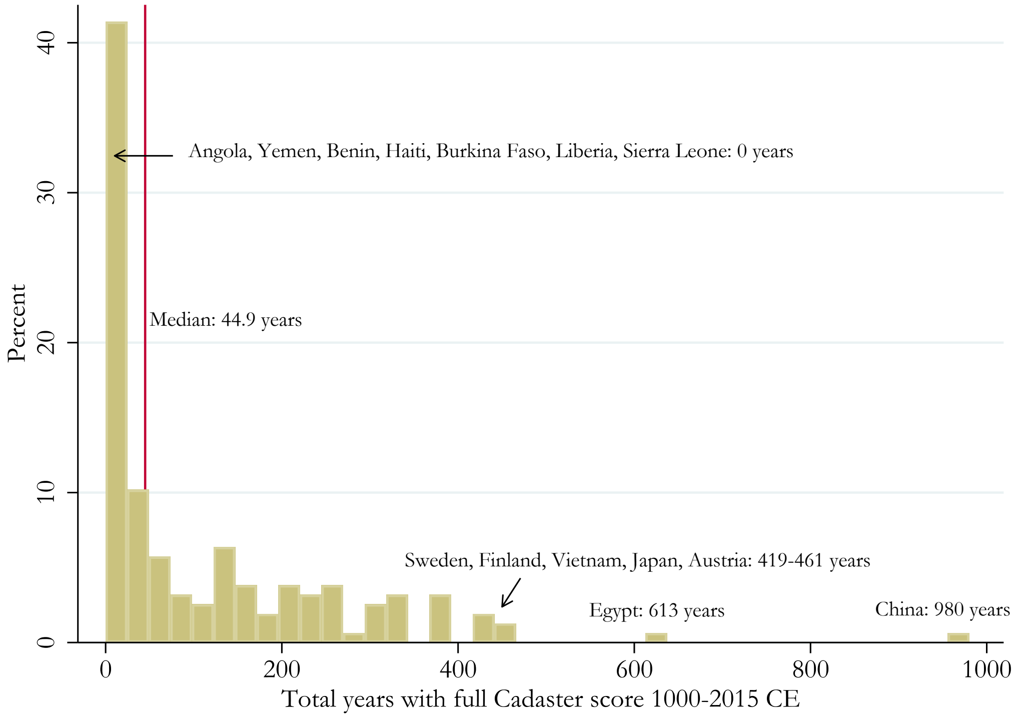
Figure 4: Evolution of *Cadaster* over time across world regions



Note: The figures show the time series of *Cadaster* for six world regions between in 1000-2015

and in the conceptual framework, we reviewed the rationales for such a hypothesis, many of which find empirical support in micro studies such as Besley (1995), Galiani & Schargrodsky (2010), Libecap & Lueck (2011a): increased investment, reduction in the resources needed to defend one's land, facilitation of land market transactions, higher value of land and better

Figure 5: Distribution of aggregate *Cadaster* scores across 157 countries



Note: The figure shows a histogram of the distribution of the aggregate "total years" with full cadaster scores (*Cadaster*=1) for 157 countries. The data is constructed by summing up all country-year *Cadaster* scores for each country.

access to credit.

4.1 Long-run economic growth

Finding reliable data on economic growth all the way back to 1000 CE posits a great challenge. Two of the most commonly used data bases 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 in the Maddison Project. 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). We use the Maddison Project's database from 2018, thereafter referred to as *MPD 2018*, as our primary data source.

As our outcome variable, we use annual real GDP per capita for all available years back to 1000 CE. This measure is available for an unbalanced panel from 4 observations in the year

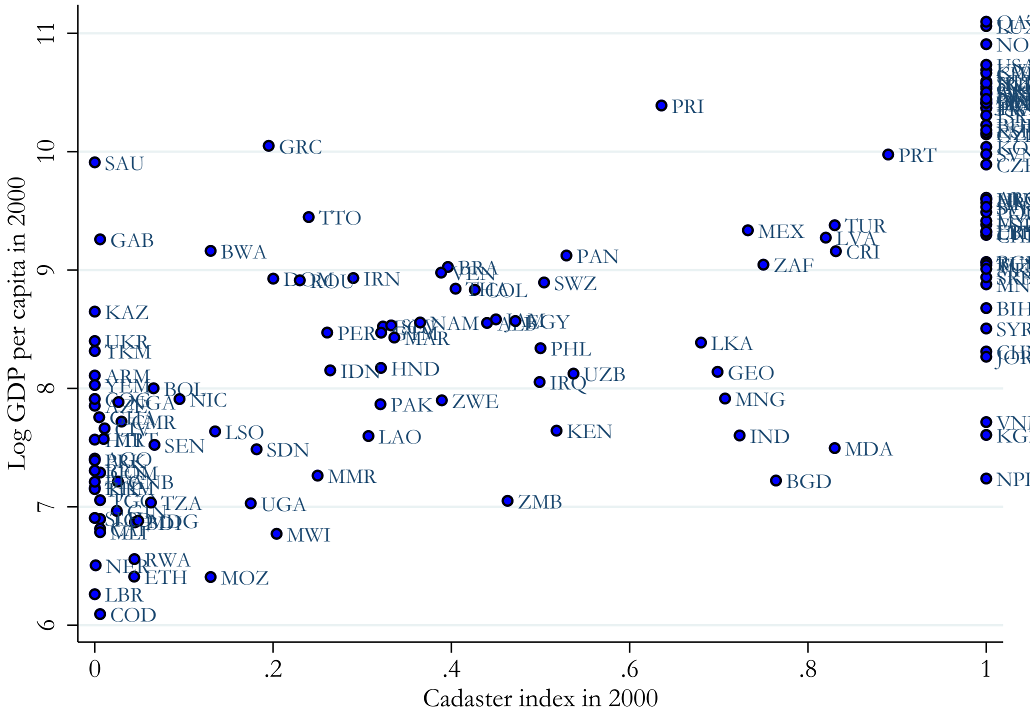
1000 to 153 observations in 2015. The longest consecutive annual time series on GDP per capita levels are those of the United Kingdom (from 1252), France (1280), Sweden (1300) and the Netherlands (1348). *MPD 2018* provides two main time series of real GDP per capita: *CGDPpc* and *RGDPNApc*. Both series are expressed in 2011 US dollars. However, in constructing *CGDPpc*, the researchers allow (implicit) relative prices used for the cross-country comparisons to differ over time. The primary advantage of this measure is that it allows for more reliable comparisons of standards of living across countries during a given year. On the other hand, *RGDPNApc* follows the traditional methodology in previous versions of the *MPD*, where the growth rates of GDP per capita track the growth rates given in the National Accounts. Furthermore, *RGDPNApc* relies on a single cross-country price comparison for 2011 (Bolt et al., 2018, p. 5). *CGDPpc* is thus primarily suitable for cross-country income levels comparisons, whereas *RGDPNApc* is more suitable for comparing growth rates over time. In other words, the *RGDPNApc* series is the most suitable for studying the within-country variation in growth rates, which is the main reason why we use it as our primary outcome variable. The Pearson correlation coefficient for the two series among 17,090 annual country-year observations in our sample is 0.938.

To get a first sense of the general static cross-country association between the existence of a cadastral system and contemporary levels of economic development, Figure 6 shows a scatter plot with log GDP per capita (*CGDPpc* from *MDP 2018*) on the vertical axis and *Cadaster* on the horizontal axis for 145 countries with available data in the year 2000. Two things are noteworthy: first, that the distribution of *Cadaster* is bimodal in character with a great number of countries having a full cadaster score = 1 and many countries having a score at 0, as well as a number of countries in a transition between the two modes. Second, there is a very clear positive correlation between income per capita and the existence of cadastral institutions. On average, countries with a full cadastral system have a GDP per capita that is about 225 percent higher than countries without a cadastral system.[10]

However, there are many reasons for why such an association should not necessarily be interpreted as a causal relationship. For instance, there might be reverse causality since countries with greater income levels might have more available resources to create a cadastral system. It

[10]If we fit a linear regression line, the coefficient would be roughly 2.25 with a t-value>13 and a $R^2 = 0.55$

Figure 6: Correlation between *log GDP per capita* and *Cadaster* for 145 countries in 2000



Note: The figure shows a scatter plot of log GDP per capita on the vertical axis (measured by the *CGDPpc*-series for cross-country comparisons in MDP 2018) and our *Cadaster* indicator, both measured in the year 2000.

might also be the case that some omitted variable X – say a change in agricultural technology – actually drive both income levels and cadastral institutions.

To address this issue we exploit a dynamic model for GDP per capita where we can control for country and year fixed effects, as well as for trends in GDP levels before a cadastral reform, as our primary research design. Such a dynamic model can be specified in a number of different ways. In order to "tie our hands" against the temptation of using a dynamic model that gives us the most clear-cut results, we chose to adopt the basic empirical strategy of a strongly related paper published recently in the *Journal of Political Economy* (Acemoglu et al., 2019). In that paper, the main independent variable is a dichotomous institutional variable (*Democracy*), constructed in a way similar to our *Cadaster* indicator. The main difference is that our institutional variable is documented for a much longer period, which makes it necessary for us to use a different source of GDP data (*MPD 2018*, rather than *World Development Indicators*). As discussed above, our *Cadaster* indicator also has intermediate steps (introduction of a narrative cadaster, etc).

4.2 Main results: Income level regressions

Our first and main econometric specification is given in equation (1) where y_{it} is the level of log GDP per capita in country i in year t, C_{it} is our *Cadaster* indicator, α_i is a country fixed effect, δ_t is a year fixed effect, and ϵ_{it} is an error term that includes all other time-varying effects on GDP per capita. As usual, 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 year-specific effects (for instance, an international downturn in the business cycle) and that α_i will absorb the effect of time invariant country characteristics, such as geographical factors, in the usual manner. Just as Acemoglu et al. (2019), we 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. The lagged values of y_{it} are further assumed to pick up the impact of a range socio-economic factors that may have impacted on both GDP and *Cadaster*. Such confounding factors might, for example, be levels of agricultural technology or productivity. The main parameter of interest in (1) is β, which we expect to be positive. If we, for instance, consider a cadastral reform leading to a change in C_{it} from 0 to 1, the interpretation is that β shows the percentage increase in GDP per capita in year t that results from that reform.

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

What is the long-term impact of such a drastic cadastral reform? As described in Acemoglu et al. (2019), the cumulative effect of a reform several years ahead can be described by a ratio of estimates as in equation (2):

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

If, for instance, $\beta = 2$ so that a full cadastral reform leads to an immediate increase in GDP by 2 percent, and if $\gamma_1 = .98$ with $L = 1$, 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. In the regressions below, we will report this long-run calculation in all specifications based on equation 1.

We use the standard within estimator to estimate the impact of *Cadaster* on GDP per capita. The main results are shown in 1, using the log of *RGDPNApc* from *MPD 2018* as our dependent variable, as motivated above. Given very few country-year observations before 1500 AD, we divide up the sample in three periods that all end in 2015 but with three different starting years; 1500, 1900 and 1950. Columns (1)-(2) show the estimates for β, multiplied by 100 so that they can be interpreted as percentages, and the coefficient for γ_l, using respectively one and four lags in the dependent variable. The estimates .515 and .470 indicate that income per capita increases with close to half a percent as an immediate result of the reform, but none of the estimates are significant. A standard pattern in the table is further that the coefficient for y_{t-1} is close to unity and significant. For this early period, systematic annual GDP per capita data is available for four European countries.

In columns (3)-(4), we run the same regressions for the 1900-2015 period, with the sample shrinking to 11,252 and 10,863 country-year observations respectively, but it also means that we can follow the growth rates of many more countries (39 countries have GDP data for 1901). The estimates for *Cadaster* now rise substantially to 1.68-2.00 and become significant at the 5-percent level. Also the long-run effect is large and significant and amounts to a 68.44 percentage increase of a permanent full reform in column (4).

From the 1950s the GDP time series data is available for more than 120 countries. The estimates of β reach an even higher level in the range 2.16-2.95 in columns (5)-(8).[11] Our main specification with $L = 4$ in column (7) has a statistically significant estimate of 2.16. The long-run impact of a full cadastral reform is an increase in GDP per capita of about 85 percent. In Table (5) we compare the long-run effect of *Cadaster* with that of *Democracy* in Acemoglu et al (2019).

The reason that our estimates in Table 1 are quite high might be partially due to the fact that our *Cadaster* variable does not have a dichotomous construction, but often moves step-wise between 0 and 1, as shown in some of the graphs above. In total, our data record 261

[11] In column (8), we include eight lags of the dependent variable.

Table 1: Effect of *Cadaster* on (Log) GDP per capita, 1500-2015

	Dependent variable: Log GDP per capita							
	1500-2015		**1900-2015**			**1950-2015**		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Cadaster	.515	.470	2.00**	1.68**	2.95***	2.49***	2.16***	2.28***
	(.544)	(.502)	(.861)	(.712)	(1.05)	(.846)	(.815)	(.856)
y_{t-1}	.979***	1.05***	.981***	1.14***	.981***	1.20***	1.18***	1.20***
	(.003)	(.027)	(.003)	(.025)	(.003)	(.038)	(.035)	(.040)
y_{t-2}		-.058**		-.119***		-.223***	-.132***	-.164***
		(.024)		(.030)		(.037)	(.044)	(.048)
y_{t-3}		.012		-.020			-.026	-.014
		(.024)		(.026)			(.032)	(.027)
y_{t-4}		-.031*		-.023			-.051***	-.057***
		(.017)		(.019)			(.017)	(.021)
Long-run	25.00	19.53	104.06**	68.44**	159.16***	111.85***	85.46***	76.23***
effect	(26.27)	(20.53)	(41.83)	(27.76)	(50.49)	(34.38)	(29.99)	(27.28)
N	15,550	15,050	11,252	10,863	9032	8928	8719	8288
Countries	150	150	150	150	150	150	150	150

Note: This table presents the within estimates of the effect of *Cadaster* on *log GDP per capita* for three different time intervals. The reported coefficient for *Cadaster* is multiplied by 100. Estimates of all included lags of log GDP per capita are included in all columns except in column (8) where we include 8 lags of y_t. 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 up to 150 countries. *** p<0.01, ** p<0.05, * p<0.1

larger changes in the *Cadaster* (greater than an absolute change of 0.1 in either direction) and a drastic change from 0 to 1 has only happened on 40 occasions in history. The mean level of change in the index is around 0.3. Using the estimate in column (7), a typical partial reform, increasing the level of *Cadaster* by 0.3, would lead to an instantaneous increase in GDP per capita by 0.65 percent.

4.3 Growth regressions

Our second empirical strategy is to first-difference the income levels equation in (1) and instead 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. More specifically, the econometric equation that we employ is given by equation (3). As before, we control for between 1-8 lags of the dependent variable, year and country fixed effects and study the same time period. 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. The estimates for the 1500-2015 period are positive, but not significant. The coefficients for *Cadaster* for the 1900-2015 period are positive, around 1.60 in magnitude and significant at the 5-percent level. As was the case in Table 1, the coefficients rise in the later period 1950-2015 to range between 1.82-2.07, depending on the number of lags in the dependent variable included. In the main specification in column (7), a full cadastral reform increases the GDP growth rate by 1.86 percentage points, which is a sizeable effect. A comparison of the estimates of the effects of full cadaster to those of full democracy in Acemoglu et al. (2019), obtained using identical specification, suggests that the effects are of a similar magnitude (1.86 vs 1.27 percentage points), with the impact of cadastral reform being once again higher. A mean level of cadastral reform of 0.3 is associated with an increase in growth rates by 0.56 percentage points.

4.4 Robustness

In this subsection of the empirical analysis, we briefly check the robustness of our main results in Table 1. Our first approach is to analyze: (i) whether cadastral reforms influence income levels with a lag, as is the case with the investment share (Table 3), (ii) whether a different binary indicator of a full cadastral system changes results, and (iii) whether the estimate of our cadaster indicator remains significant when we include additional country- and year-specific control variables commonly used in the literature.

Table 3 reports the results of this exercise, where the first three columns check the impact of lagged levels of *Cadaster*. The coefficient of *Cadaster* becomes insignificant already with two lags, and gradually decreases from column (1) to column (3). This suggests that the main effect of a cadastral reform is immediate rather than deferred.

We mentioned earlier that the main study that we compare with, i.e. Acemoglu et al. (2019),

Table 2: Effect of *Cadaster* on the growth rate of GDP per capita, 1500-2015

	Dependent variable: Growth rate of real GDP per capita							
	1500-2015		**1900-2015**		**1950-2015**			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Cadaster	.520	.550	1.63**	1.60**	2.07**	1.97**	1.86**	1.82**
	(.469)	(.471)	(.740)	(.776)	(.856)	(.867)	(.881)	(.921)
Δy_{t-1}	.065**	.068**	.153***	.154***	.214***	.203***	.207***	.225***
	(.028)	(.028)	(.026)	(.027)	(.038)	(.035)	(.038)	(.040)
Δy_{t-2}		.008		.031		.070**	.067**	.054*
		(.021)		(.022)		(.030)	(.031)	(.030)
Δy_{t-3}		.016		.006			.034*	.041**
		(.017)		(.019)			(.018)	(.017)
Δy_{t-4}		-.001		-.002			-.009	-.018
		(.011)		(.013)			(.013)	(.013)
N	15,382	14,884	11,121	10,734	8928	8824	8612	8180
Countries	150	150	150	150	150	150	150	150

Note: This table presents the within estimates of the effect of *Cadaster* on the growth rate of GDP per capita for three different time intervals. The reported coefficient for *Cadaster* is multiplied by 100. Estimates of all included lags of the growth rate of GDP per capita are reported in all columns except in column (8) where we use 8 lags of y_t. 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 up to 150 countries. *** p<0.01, ** p<0.05, * p<0.1

used a dichotomous democracy variable as their main independent variable of interest, whereas our *Cadaster* indicator can assume several values ranging from 0 and 1, depending on the type of cadaster and the completeness of reform. In column (4), we introduce a dichotomous indicator equal to 1 when the country attains complete cadastral institutions (i.e. $Cadaster = 1$). As expected, the estimate in column (4) falls to 1.39 from 2.16 in column (1) with a p-value of 0.075. The long-run effect, calculated as in equation 2, would suggest an increase in GDP levels of 54.9 percent. This is still larger than the long-run effect of democracy in Acemoglu et al. (2019), but much closer to their estimate of 21 percent.

In column (5), we include one of the most commonly used variables for measuring the level of democracy – *Polity2* from the *Polity IV* dataset – ranging between +10 for full democracies to -10 for full autocracies (Marshall et al., 2019). One might be concerned that cadastral reforms could potentially pick up the signal from democratizations, which is the key institutional change of interest in Acemoglu et al. (2019). In column (5) we see that the estimate for *Cadaster* does

Table 3: Robustness analysis I: Lagged levels of *Cadaster* and time varying control variables, 1950-2015

	Dependent variable: Log GDP per capita 1950-2015								
	Lags in *Cadaster*				**Controls**				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Cadaster(t)	2.16***				2.64***	2.72**	2.86***	3.52***	3.03***
	(.815)				(.986)	(1.12)	(.890)	(1.10)	(.773)
Cadaster(t-1)		1.10*							
		(.565)							
Cadaster(t-2)			-.155						
			(.598)						
Full *Cadaster(t)*				1.39*					
				(.78)					
Polity2					-.000				-.000**
					(.000)				(.000)
Liberal dem.						.004			
						(.007)			
Log Pop. dens.							-.018***		-.030***
							(.006)		(.007)
Infant mortality								-.000**	-.000***
								(.000)	(.000)
y_t, lags 1-4	√	√	√	√	√	√	√	√	√
N	8719	8732	8745	9069	7591	7509	6818	6704	6502
Countries	150	150	150	153	148	145	147	147	147

Note: The table reports the within estimates of the effect of different lags of *Cadaster* and a standard set of control variables on log GDP per capita for the 1950-2015 period. Unbalanced panel including 145-153 countries. The reported coefficients for *Cadaster* are multiplied by 100. 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

not change substantially and remains significant whereas *Polity2* has no discernible effect. The same effect is observed for an alternative variable for liberal democracy from the V-Dem Institute (Coppedge et al., 2019) that we utilize in column (6).

Could it be the case that cadastral reforms are somehow 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 (7), log population density has a negative and significant impact on log GDP per capita but the coefficient for *Cadaster* remains of similar magnitudes as before and is significant when population density is included.

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 (8) we include infant mortality per 1000 live births as a proxy for state capacity in health care. Interestingly, the estimate for *Cadaster* rises even when infant mortality is included. As expected, years with a high infant mortality are associated with lower levels of GDP per capita within countries. In column (9) the estimates for all three control variables – regime type, population density and state capacity – are statistically significant, and *Cadaster* remains around 3 and its positive impact is measured with precision.

As our second approach to checking robustness, we replace the *CGDPpc* indicator of GDP per capita from Table 1 with *RGDPNApc*. As discussed above, the latter is constructed in a somewhat different way in order to be mainly suitable for cross-country income levels comparisons during a particular year. We include this variable in a robustness analysis (Table 4), where all specifications are otherwise identical to those in Table 1.

The results in Table 4 are somewhat striking in the sense that the estimates of our *Cadaster* variable are higher and with higher t-values throughout than in Table 1. For instance, the estimate in column (2) indicates that GDP per capita tended to increase by 1.36 percent in response to a full cadastral reform already during the 1500-2015 period. In the main specification in column (7), the coefficient for *Cadaster* is 4.67 and the long-run effect of introducing a cadastral institution is an increase in GDP of 136 percent (compared to 85 percent in the same column in Table 1). The effect seems implausibly high and could potentially be due to the difference in the price deflator between the two time series.

As a third robustness check, we use the same data as Acemoglu et al. (2019). This limits our analysis to a shorter time period from 1960, but allows us to directly compare the estimates for their *Democracy* variable with our *Cadaster* variable. Table 5 reports the results of this analysis. Columns (1)-(2) replicate Acemoglu et al. (2019)'s specifications in columns (1) and (3) Table 2. When we instead introduce *Cadaster* in columns (3)-(4) in otherwise identical specifications (but with fewer country-year observations), the coefficients are substantially higher and are significant at least at the 10-percent level. The long-run effect is a 53.25 percent increase in GDP per capita (column (4)), which is more than double the effect of *Democracy* (21.24) in column (2). If we consider a typical increase in our score by 0.3, the estimate in column (4) implies an immediate effect of a cadastral reform of a 0.58 percent rise in GDP per

Table 4: Robustness analysis II: Effect of Cadaster using an alternative measure of GDP per capita, 1500-2015

	Dependent variable: Log GDP per capita (CGDPpc)							
	1500-2015		**1900-2015**		**1950-2015**			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Cadaster	1.45*	1.36*	3.88***	3.54***	5.35***	5.11***	4.67***	5.08***
	(.762)	(.710)	(1.14)	(.996)	(1.35)	(1.23)	(1.15)	(1.26)
y_{t-1}	.976***	1.02***	.975***	1.06***	.973***	1.07***	1.06***	1.06***
	(.003)	(.020)	(.003)	(.020)	(.004)	(.025)	(.023)	(.025)
y_{t-2}		-.011		-.031		-.101***	-.008	-.019
		(.024)		(.030)		(.025)	(.037)	(.038)
y_{t-3}		.008		-.021			-.024	-.023
		(.025)		(.027)			(.032)	(.032)
y_{t-4}		-.040**		-.034*			-.058***	-.041*
		(.016)		(.017)			(.018)	(.024)
Long-run effect	61.20**	49.41**	158.33***	119.30***	194.79***	169.40***	135.79***	119.27***
	(30.80)	(24.64)	(41.59)	(31.48)	(43.80)	(36.84)	(31.41)	(28.59)
N	15,279	14,777	11,254	10,863	9032	8928	8719	8288
Countries	150	150	150	150	150	150	150	150

Note: The table reports the within estimates for *Cadaster* on the alternative measure of Log GDP per capita (*CGDPpc*) from the Maddison dataset for three different time periods. Unbalanced panel including up to 151 countries. The reported coefficients for *Cadaster* are multiplied by 100. All models include and different lags of log GDPpc, except for column (8), where 8 lags of y_t are used (not reported). All specifications include country and year fixed effects. Standard errors are in parentheses, clustered at the country level. *** p<0.01, ** p<0.05, * p<0.1

capita, which is very close to the equivalent estimate at 0.65 in Table 1.

Column (5) reports the results of a "horse race" between the two institutional variables. It is plausible to assume that there could exist collinearity between *Democracy* and *Cadaster* (the Perason correlation is about 0.38), as democratic and cadastral reforms could be seen as strengthening the cluster of "inclusive institutions" in a country since they both strengthen economic rights. On the other hand, we know that such autocratic countries as China and Vietnam have long history of cadasters but no meaningful experience of democracy. Turning to the results, we see that both *Democracy* and *Cadaster* remain significant in column (5) and that the coefficient for *Cadaster* is considerably higher. When we interact the two variables (column (6)), *Democracy* is no longer significant, whereas the positive estimate for the interaction term

Table 5: Robustness analysis III: Comparative effect of *Cadaster* and *Democracy* using data from Acemoglu et al. (2019), 1960-2010

	Dependent variable:								
	Log GDP per capita						**Growth rate GDP pc**		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Democracy	0.973***	0.787***			0.656***	0.319	1.269***		1.106***
	(0.294)	(0.226)			(0.240)	(0.307)	(0.243)		(0.313)
Cadaster			3.282**	1.943*	2.164*	1.891*		1.885*	1.967*
			(1.303)	(1.079)	(1.129)	(1.141)		(1.060)	(1.105)
Democracy x Cadaster						0.837*			0.079
						(0.493)			(0.562)
y_{t-l}, lags	1	4	1	4	4	4			
Δy_{t-l}, lags							4	4	4
Long-run effect	35.59**	21.24***	116.76**	53.25*					
	(14.00)	(7.21)	(46.54)	(29.11)					
N	6790	6336	5835	5403	5365	5365	6178	5259	5229
Countries	175	175	145	145	145	145	175	145	145

Note: The table reports the within estimates of *Democracy* and *Cadaster*, using Acemoglu et al. (2019)'s data from 1960-2010. Unbalanced panel including up to 175 countries. The dependent variable is *Log GDP per capita* in columns (1)-(6) and the *Growth rate of GDP per capita* in columns (7-9). The reported coefficients are multiplied by 100. All models include a varying number of lags of the dependent variable and country and year fixed effects. Standard errors, clustered at the country level, in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

suggests that cadastral reforms have a stronger effect on GDP levels in democratic societies.

Lastly, in columns (7)-(9), we employ the growth rate of GDP per capita as the dependent variable. Column (7) replicates the result for *Democracy* in Acemoglu et al. (2019)'s Table 3, column 3. Column (8) reports the estimate for *Cadaster*, which is again higher, albeit estimated with less precision than *Democracy.* The interaction term between the two variables of interest has an insignificant coefficient (Column (9)), but individually they enter statistically significant, suggesting that *Democracy* and *Cadaster* have separate and non-complementary effects on economic growth.

4.5 Country case studies

In this section, we conduct 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.[12] In this analysis, the dependent variable is the annual growth rate of GDP per capita. All specifications include four lags of the dependent variable in order to control for pre-trends, in line with the preferred specifications in Tables 1-2. Columns (2), (4), (6), and (8) include linear time trends to filter out the effect of potential long-run trends in the growth rate within the period. Together with the estimates, we report the robust standard errors from an OLS regression and the Newey-West standard errors with four lags that correct for heteroskedasticity as well as potential autocorrelation.[13]

The results in Table 6 are substantively similar to those in Table 2. In United Kingdom, where the time series has 759 annual observations, the growth rate increases by 1.32-1.8 percentage points as a result of a full reform.[14] In France, the estimate is 1.2-1.3 and significant at the 10-percent level. In Sweden, the overall effect is unclear, as the estimate's sign changes once a time trend is accounted for. The Netherlands display the strongest effect where an increase of the *Cadaster* indicator from 0 to 1 is associated with a 1.86-2.93 percentage point increase in the growth rate.

Furthermore, we examined the impact of the introduction of a full mapped cadastral system

[12] In all these countries, the earliest available data predate 1500 CE and several annual observations were not included in the analyses reported above.

[13] Unfortunately, Newey-West standard errors are not available for France and Netherlands due to missing data for some years.

[14] With Newey-West standard errors the level of significance falls.

Table 6: Country case studies of the effect of *Cadaster* on the growth rate of GDP per capita, all 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	1.80***	1.32**	1.20*	1.30*	1.00	-2.62*	1.86**	2.93**
	(.56)	(.57)	(.65)	(.68)	(.67)	(1.42)	(.73)	(1.37)
	[.74]	[.71]	n.a.	n.a.	[.63]	[1.29]	n.a.	n.a.
Δy_{t-l}, lags 1-4	√	√	√	√	√	√	√	√
trend		√		√		√		√
N	759	759	696	696	711	711	652	652
R^2	.12	.13	.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 reported coefficients for *Cadaster* are multiplied by 100. All specifications include lags of the growth rate of GDP per capita (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, where available. *** p<0.01, ** p<0.05, * p<0.1 based on t-values from robust standard errors.

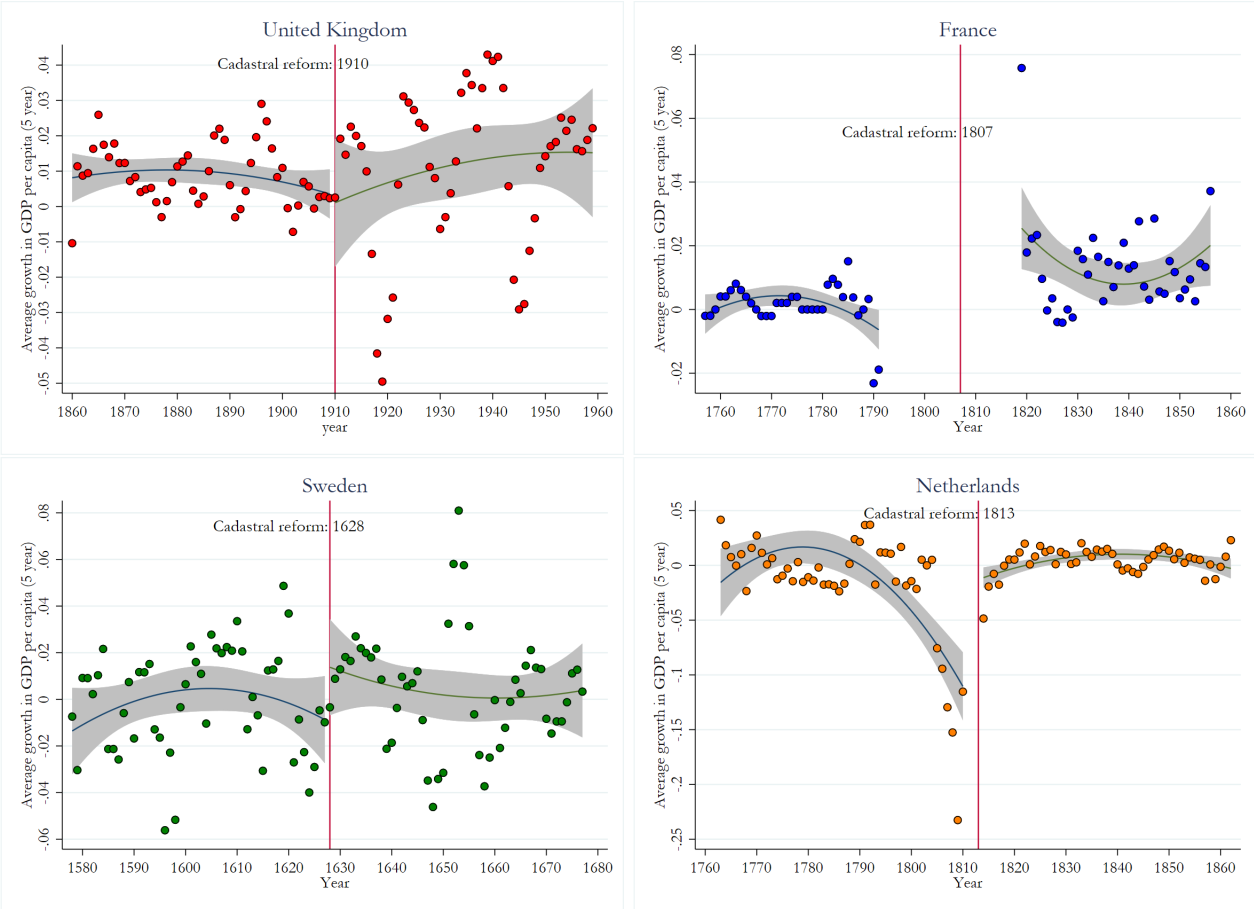
in greater detail by conducting an event analysis. Figure 7 shows the development of the five-year moving average of growth rates of GDP per capita during a century-long window 50 years before and after the year of transition to a full national cartographic cadaster.[15] We have included non-linear fitted regression lines with confidence intervals at 5-percent level.

Figure 7 offers several noteworthy observations. First, in all four countries the reform was preceded by a falling trend in GDP per capita growth. Hence, we cannot rule out that cadasters could have been introduced at least partially in response to economic and political hardships.

Second, in all countries the cadastral reform was carried out right before or during a major war episode. While in the United Kingdom, the 1910 reform happened just before World War I, in Sweden, the 1628 reform happened when the country was about to embark on a major engagement 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, which caused a hiatus in the recording of aggregate production statistics in both countries. These observations are in line with a large literature, pioneered by Tilly (1990b), documenting that the strengthening of

[15]We focus on the year when our *Cadaster* indicator reaches its maximum score 1. Partial reforms (for instance the introduction of a narrative cadaster) have often been carried out before this date. For instance, in Sweden, narrative cadaster existed already in the 1530s, while the country transitioned to a full mapped cadaster in 1628.

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



Note: The figures show event studies during a 100-year window of a full cadastral reform in United Kingdom (starting in 1252), France (1280), Sweden (1300), and Netherlands (1348). The vertical axis shows a five-year moving average of growth rates in GDP per capita. The figures show fitted polynomial regression lines with 5-percent confidence intervals before and after year of reform. France and Netherlands have missing observations around the time of reform.

fiscal capacity in Europe was caused by the war imperative.

Third, the four reform episodes suggest that cadastral reforms are often accompanied by a cluster of other institutional reforms. The transition to mapped cadaster in Sweden in 1628 was only one of several institutional innovations aimed at improving the fiscal and judicial capacity of the central government (Wetterberg, 2002). In France, the 1807 cadastral reform was carried out at the same as the wide-ranging *Code Napoleon* was introduced that would serve as a model for civil law in several countries. In the Netherlands, the reform of 1813 happened in the final years of 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 certainly also contributed to the higher post-reform growth rates in

France and the Netherlands.

Fourth, higher average growth rates after reform are not only found in France and the Netherlands, but in all four countries, confirming the tendency from the results in the Table 6.

Figure A2 in the Appendix shows a similar graph for a partial reform in a developing country, i.e. Kenya, which is one of relatively few African countries that is endowed with a substantive cadastral system. The 1982 reform was not immediately able to turn the negative trend from fiscal mismanagement during the 1970s. However, since around 2000, Kenya has experienced a steadily increasing average growth rate.

5 Mechanisms

This section briefly explores two channels through which cadastral reforms could plausibly affect economic growth: the level of the *real natural interest rate* and the *ratio of physical capital investment to GDP*. We argued above that having a secure title to one's land should imply better access to credit and a greater willingness to invest in agricultural productive capital such as ploughs, windmills and (in the 20th century) tractors. Such micro level developments on individual farms might, in turn, induce a stronger farmer demand for public goods investment such as better roads, secure market places, and eventually railroads and electrification. Along similar lines, Acemoglu et al. (2019) argue that democratization should lead to greater investment and explore it as their first intermediate channel. In our simple conceptual framework, we predicted that levels of investment should increase as a result of a cadastral reform whereas the impact on the level of the real natural real interest rate was ambiguous and might either increase or decrease depending on the strength of the investment demand and the collateralized credit supply ("de Soto" effects).

We use recently published historical time series on the real interest rate (i.e. the nominal interest rate net of inflation, in percent) from a few European countries collected by Schmelzing (2020). Data is available for three of our four country cases: the United Kingdom (1314-2012), France (1387-2012) and the Netherlands (1400-2012). The time series for the United Kingdom (Figure A3 in the Appendix) shows that the annual data display a large degree of variation and there is a strong falling trend (or "secular stagnation") as we approach current times, as discussed more thoroughly in Schmelzing (2020). In our analysis, we make use of both the annual data as well as the filtered series (which might be seen as a proxy for a more stable real natural interest rate, as in Jorda et al. (2020)).

The equation that we estimate for each of the three countries is:

$$r_t = \beta C_t + \sum_{l=1}^{4} \omega_{t-l} r_{t-l} + \sum_{l=1}^{4} \gamma_{t-l} \Delta y_{t-l} + \tau_t + \epsilon_t \tag{4}$$

The dependent variable r_t is either the annual real interest rate or a filtered average rate. We include four lags of the dependent variable and output growth rates Δy_t, in line with the main specification in the previous tables. We also include a linear time trend τ_t to control for the falling level in real interest rates.

Table 7: Country case studies of the effect of *Cadaster* on the real interest rate, all years

	Dependent variable:					
	Annual real interest rate			**Average real interest rate**		
	UK	**France**	**Netherlands**	**UK**	**France**	**Netherlands**
	(1)	(2)	(3)	(4)	(5)	(6)
Cadaster	5.134***	-1.907	7.106***	.821***	-.552	1.527***
	(1.050)	(1.672)	(1.882)	(.286)	(.425)	(.514)
	[1.20]	n.a.	n.a.	[.35]	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 the effect of *Cadaster* on the real interest rate (in percent) in three countries. 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.

Table 7 report the regression results. For the United Kingdom and the Netherlands, the estimates are positive and significant at the higest level for both dependent variables. The interpretation that follows from our conceptual framework (Figure 1) is that the *investment demand* effect is stronger than the *"de Soto"* (credit supply) effect in these countries, implying a net increase in the real natural interest rate. The estimates for France are negative but not significant. Since there is no reliable data on the user side of GDP so far back in time, we cannot assess statistically whether the cadastral reforms in the early 19th century in France and the Netherlands were accompanied by major spikes in investment.

Data on investment levels as a share of GDP are available from around 1960. We define the investment ratio in country i at time t as I_{it}. The equation that we estimate is equation (4). As before, we control for $L = 4$ lags of income, as well as country and year fixed effects. In order to check for pre-trends in the dependent variable, we also include lagged levels of investment. The main parameter of interest is, as before, the coefficient for our *Cadaster* variable, β, which we expect to be positive. However, we recognize that the impact of an institutional reform on investment might take some time to materialize through its effect on investment demand, credit supply, and the real interest rate. Hence, we estimate equation (4) by including lagged levels of C_{it}.

$$I_{it} = \beta C_{it-l} + \sum_{l=1}^{4} \theta I_{it-l} + \sum_{l=1}^{4} \gamma y_{it-l} + \alpha_i + \delta_t + \epsilon_{it} \tag{5}$$

Columns (1)-(5) of Table 8 show that the impact of *Cadaster* is not only positive, as expected, but also increases over time. Figure A4 in the Appendix shows the evolution of the estimate with 0-10 lags in *Cadaster*. The estimate peaks at 1.11 and is significant at 5-percent level after 5 years, after which it falls. A full cadastral reform is thus expected to increase the investment rate from a mean level of 23 to 24.11, five years after the reform.

Table 8: Effect of *Cadaster* on the Investment share of GDP, 1960-2015

	Dependent variable: Investment share of GDP 1960-2015					
	l=0	l=1	l=2	l=3	l=4	l=5
	(1)	(2)	(3)	(4)	(5)	(6)
Cadaster(t-l)	.560	.516	.726	.830	.972*	1.11**
	(.558)	(.587)	(.549)	(.533)	(.521)	(.535)
Inv. share, lags 1-4	√	√	√	√	√	√
y_t, lags 1-4	√	√	√	√	√	√
N	5218	5228	5237	5244	5250	5255
Countries	148	148	148	148	148	148

Note: This table reports the within estimates of the effect of *Cadaster* on *Investment share of GDP*, 1985-2015, in year t for different lags t-l of *Cadaster*. Unbalanced panel including up to 148 countries. Standard errors are in parentheses. Each specification includes country and year fixed effects, four lags of the dependent variable, and of y_t. *** p<0.01, ** p<0.05, * p<0.1

This analysis suggests that GDP is boosted after a while through the investment channel, but the immediate effects of cadastral reforms on GDP levels and growth rates detected in the previous analyses, seem to arise through some other channel. Comsumption could be one of such channels, considering that the recording of property rights to land may increase households' instantaneous assessment of their lifetime net wealth. Total factor productivity could be another potential channel, considering that output increases with a given level of labor and capital input through a more productive or efficient use of resources. We leave it for future work to explore these mechanisms further.

6 Discussion

The general tendency throughout the tables has been that our *Cadaster* indicator displays a positive and significant coefficient 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. There is some indication that investment as a share of GDP acts as an intermediate channel, but only with a time lag. We found that cadastral reforms appear to have increased real interest rates in financially developed countries like the United Kingdom and the Netherlands. The coefficient for *Cadaster* from the within panel regressions becomes more often 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 credit markets, as discussed by Besley et al. (2012). We leave this question to be explored by future research.

Taken the results in their totality, we interpret them as being consistent with our hypothesis that cadastral reforms should have a positive association with levels of GDP per capita. 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 hard 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.

7 Conclusion

In line with the literature on the importance of property rights institutions for economic growth (Acemoglu et al., 2005; North, 1990) and more specific research on the effects of improving land property rights and cadastral reforms (Galiani & Schargrodsky, 2010; Libecap & Lueck, 2011a; Yoo & Steckel, 2016), we hypothesized that cadastral reforms should have a positive impact on economic growth since they imply more secure returns on investment, a reduction in the resources needed to defend the rights to land, facilitate land market transactions and increase access to credit. Using our newly developed measure of state-administered cadastral records during 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 real interest rates and investment as a share of GDP, are affected by cadastral reforms. A deeper analysis of these and other effects such as the impact on real estate prices and government tax revenues, are natural avenues for future research.

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

In this Appendix we explain the main principles underpinning of our coding schema and provide examples. An online 90+ page long Appendix *Dates and Sources* provides a comprehensive description of the coding decisions with supporting references for all country/year observations.

A.1 Was there a state-administered cadaster?

To document the existence of a cadaster we went through several thousands sources in different languages,[16], including peer-reviewed publications, working papers, PhD theses, and reports of the professional associations of land surveyors, national governments and aid organizations.

The emergence of state-administered cadaster is usually well-documented. There is both reputable academic literature (f.e.Erba (2008); Haldrup & Stubkjær (2013); Kain & Baigent (1992); Williamson & Enermark (1996)) and documents, prepared by professional surveyors either as a service to their association (*Cadastral Template* is a description of the emergence of cadaster in 66 countries) or to their governments or aid organizations.

A.2 Narrative or mapped cadaster?

Cadasters come in two forms: narrative and cartographic. Narrative and cartographic (mapped) cadasters identify land assets differently. 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 2).

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 trade and other land-related market transactions. 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

[16] Mostly English, but also Spanish, Russian, French and Portuguese

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: Left Panel: Satellite image of land demarcation in Ohio, 2020; Right panel: Satellite image of land demarcation in Federal Capital Territory, Nigeria

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

To quantify the difference between mapped and narrative cadasters we, first, draw on the specialized literature that treats cartographic cadasters as an evolutionary development of narrative cadasters, and sees the distance between narrative and cartographic cadasters to be smaller than the distance between no cadaster and a narrative cadaster. This suggests that the weight of the narrative cadasters should be larger than 0.5. 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 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, p. 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, p.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 only 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. Another reason for weighting narrative cadasters as more than half (0.5) of the cartographic ones is because the specialized literature treats cartographic cadasters as an evolutionary development of narrative cadasters, and sees the distance between narrative and cartographic cadasters to be much smaller than the distance between no cadaster and a narrative cadaster.

A.3 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.

Coding information:

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

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, p. 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 4), 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.[17] To illustrate, after independence in 1989, 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

[17] 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)).

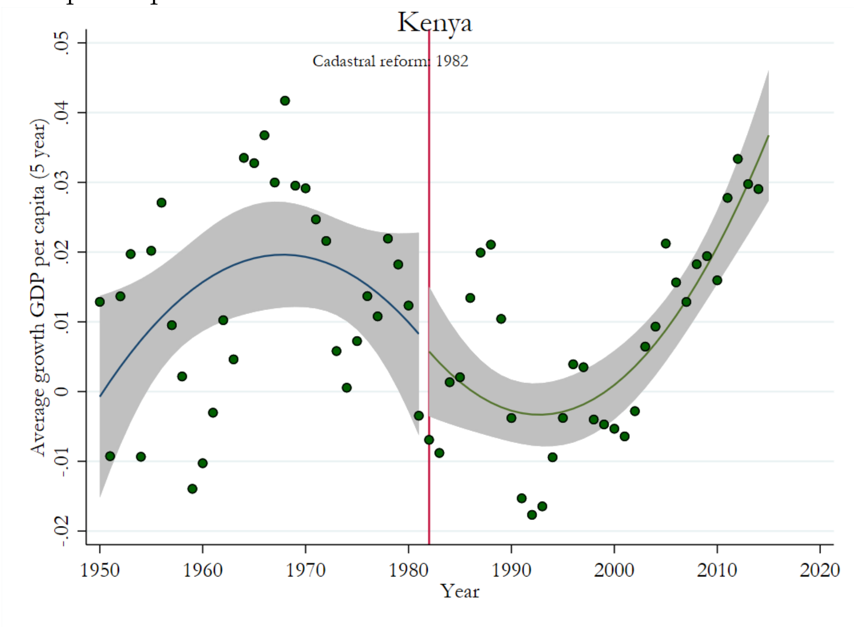
parcels in the total number of parcels — is the the most accurate measure, it is not available for all country/years. For most of the remaining country/years we have data on the implementation of rural cadasters, but the data comes in a number of different forms. First, it comes as the share of regularized 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 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 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 $z^3_{Guatemala2007} = 0.47$.

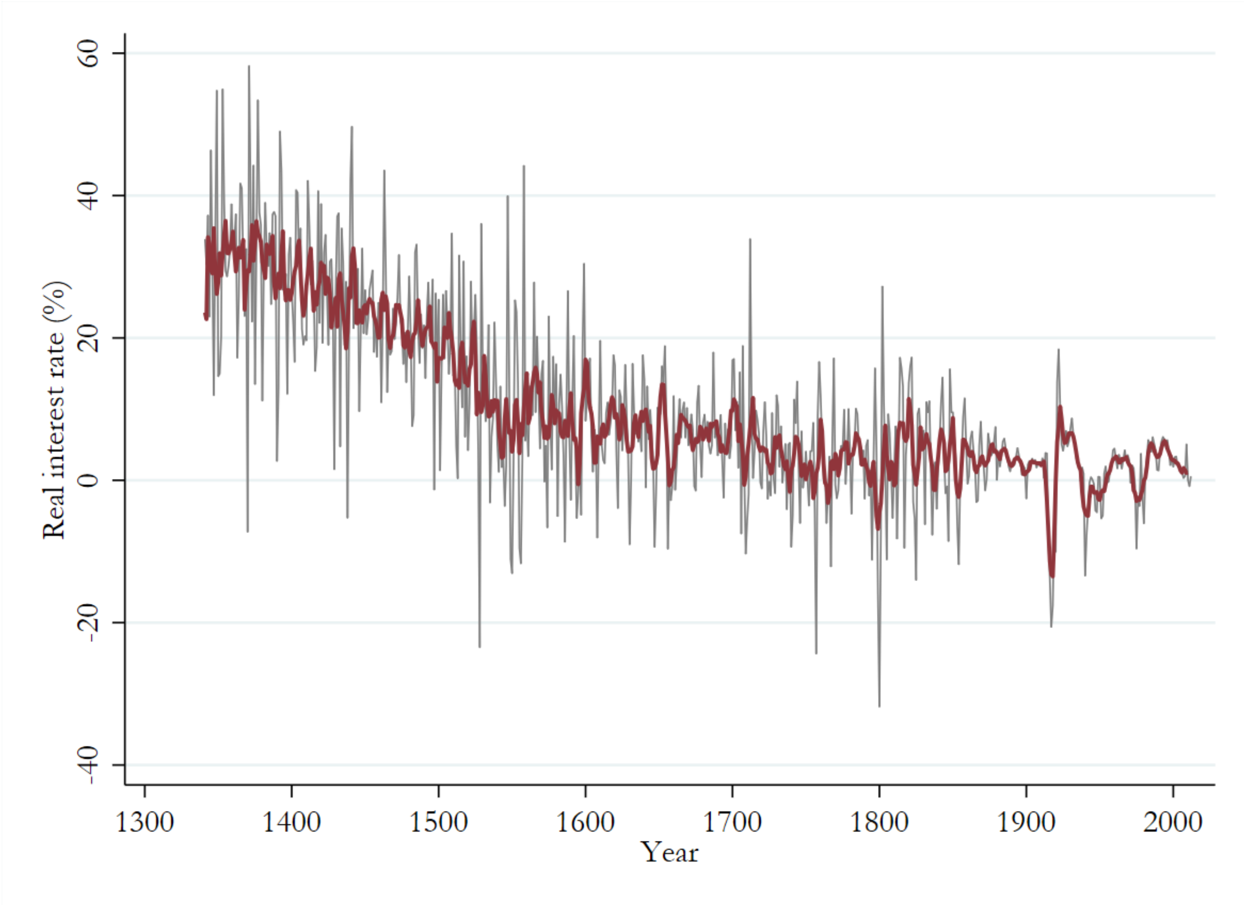
B Analysis

Figure A2: Event study of partial cadastral reform in Kenya in 1982 on average GDP growth rate per capita 1950-2015



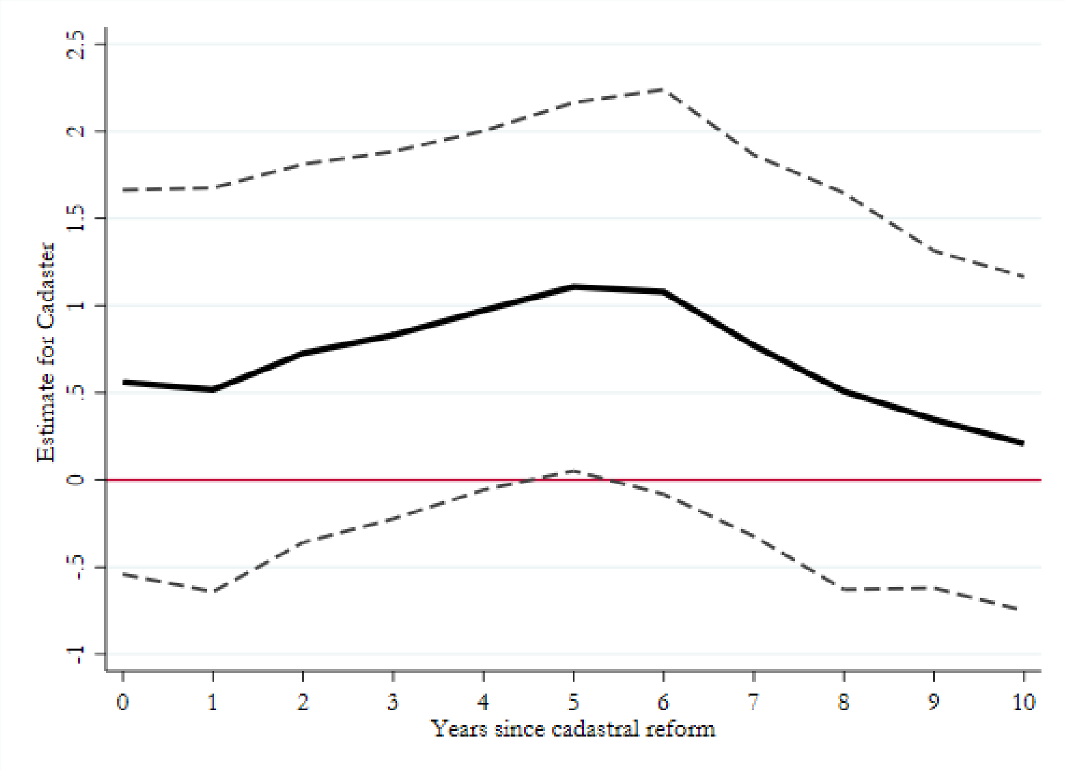
Note: The figures shows an event study of a partial reform in 1982 in Kenya on all available GDP levels 1950-2015. The vertical axis shows a five-year moving average of growth rates in GDP per capita. The figures show fitted polynomial regression lines with 5-percent confidence intervals before and after year of reform.

Figure A3: Real interest rate in the United Kingdom, 1314-2012



Note: The figure shows the real interest rate in United Kingdom during 1314-2012. The thin grey line shows annual rates and the thick red line shows a five-year moving average. Data source: Schmelzing (2020).

Figure A4: Response of *Cadaster* on Investment share of GDP per capita, 1960-2015



Note: The figure shows the response of *Cadaster* on Investment share of GDP per capita with up to ten lags in *Cadaster* as specified in equation 5.