

# Spillovers in State Capacity Building: Evidence from the Digitization of Land Records in Pakistan\*

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## Abstract

Digitization reforms have been hailed as an effective way to strengthen state capacity. However, digitization can also disrupt the organization of bureaucracies. Using a unique administrative dataset on agricultural taxation and surveys of local bureaucrats from Punjab, Pakistan, we show that digitization reforms can have unintended consequences for state capacity. We exploit the staggered rollout of the digitization of land records in Punjab to show that digitization had a negative effect on tax collection. The fall in taxes was not due to a decrease in the tax base. Instead, digitization affected the bureaucracy's capacity to collect taxes. The paper thus sheds light on the importance of understanding state capacity development from an organizational perspective.

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# 1 Introduction

Strong state capacity is essential for economic development. An effective approach to strengthening it is to introduce technology in bureaucracies. In addition to easing market frictions (Beg, 2022), technology can improve the productivity of bureaucrats and address a range of asymmetric information issues. It has helped to reduce agency problems between bureaucrats and their principals (Duflo et al., 2012; Lewis-Faupel et al., 2016; Callen et al., 2020a; Dal Bó et al., 2021; Debnath et al., 2023), to improve the reliability of information on taxpayers (Ali et al., 2021; Okunogbe and Pouliquen, 2022; Brockmeyer and Sáenz Somarriba, 2022; Dzansi et al., 2022), or the identification of welfare recipients (Muralidharan et al., 2016a).

However, the introduction of technology also disrupts the organization of bureaucracies. As public administration scholars have noted, digitization “reconfigures public sector organizations in fundamental, although uneven, ways” (Plesner et al., 2018). Digitization reforms can change the relationships between different bureaucratic agencies (Di Giulio and Vecchi, 2023) and increase specialization (Gundhus et al., 2022). These changes can affect functions not directly targeted by the introduction of technology.<sup>1</sup> The reorganization of these functions can impact bureaucrats’ sense of autonomy and their relationship with the public (Pors and Pallesen, 2021) or result in the displacement of corruption onto other activities (Yang, 2008; Muralidharan et al., Forthcoming). Whether these changes are sufficiently disruptive to limit the benefits of technological reforms remains an open question.

In this paper, we seek to understand whether the organizational changes brought about by the introduction of technology in bureaucracies can weaken state capacity. We study this question in the context of the digitization of land records in Punjab, Pakistan, and show that the reform had a negative impact on

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<sup>1</sup>For instance, a digitization reform to improve emergency policing in the Norwegian police shifted the task of information processing from local officers to centralized intelligence teams, which in turn negatively affected community policing (Gundhus et al., 2022). In the UK, the digitization and consolidation of the benefits system led some civil servants to report that “legal advisors are now doing the data entry rather than the administrative assistants. This in turn means that we can’t do what we are supposed to do, advising magistrates on all things related to the law, procedure, evidence, sentencing [...]” (Gill, 2023).

the ability of the state to collect taxes. This negative relationship is not due to the direct effect of the digitization reform on the tax base but to its indirect effect on the capacity of bureaucrats to collect taxes.

Digitizing land records is a popular way of leveraging technology to strengthen state capacity. From 2010 to 2019, fifty-two economies computerized their land registries both in developing and developed countries, using significant resources in the process.<sup>2</sup> In most countries, these reforms have also resulted in important bureaucratic reorganizations. For example, the computerization of Denmark's land registry in 2011 was accompanied by the centralization of 82 separate registration offices in charge of registering not only land records but also other legal services such as marriage contracts (Nielsen and Kristiansen, 2008). Similarly, the Digital India Land Records Modernization Program (DILRMP) not only computerized land records but also integrated land record services with registration services.<sup>3</sup>

To study the impact of the bureaucratic reorganization induced by digitisation reforms, we exploit the staggered rollout of the digitization of land records across districts of Punjab. Since this reform was carried out in three phases between 2011 and 2014, we use a differences-in-differences design to identify the causal effect of the digitization reform on the amount of tax collected by the state. We digitized a novel administrative data set of rural agricultural taxes which we combine with data on the rollout of the reform to test this effect. We complement this data with satellite data on vegetation cover, survey data from local farmers, and unique data on the career trajectory of individual bureaucrats to separate the effect of the reform on the tax base from its effect on the bureaucrats' capacity to collect taxes.

We begin by documenting how the digitization reform affected the bureaucracy. First, bureaucrats who were in charge of tax assessment, tax collection, and land records management before the reform were no longer responsible for land records after it. Second, a large portion of bureaucrats (46%) reported that digitization negatively impacted tax collection. Of those, 57% reported that this was due to lower influence on taxpayers. Finally, bureaucrats lost a lucrative source of

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<sup>2</sup>Source: Doing Business Database, World Bank, <https://subnational.doingbusiness.org/en/data/exploretopics/registering-property/good-practices>.

<sup>3</sup>See <https://dolr.gov.in/programmes-schemes/dilrmp-2/>.

bribes: the proportion of bureaucrats who agreed that citizens bribed officials for land titles dropped from 48% to 33% after digitization.

We then show our main result: that this reform had a significant impact on the state's ability to collect taxes. Digitization of land records led to an 84% decrease in tax collection in districts in the first two phases of the program relative to those in the third phase, which were not yet digitized. The modernization of state capacity not only failed to translate into higher tax revenues for the state, it actually reduced them. These results are robust to using different definitions of the timing of digitization, to different assumptions about differential pre-treatment trends (Rambachan and Roth, 2023), and to using estimators that account for treatment effect heterogeneity in staggered differences-in-differences designs (Callaway and Sant'Anna, 2021; Sun and Abraham, 2021; Borusyak et al., 2024).

A decrease in tax revenue does not necessarily indicate a decrease in fiscal capacity. It is possible that the tax base decreased while the ability to collect taxes remained unchanged. We show that this was not the case here. The tax we study is levied on farmers based on cultivated area or profits and we find that the reform had a positive but not statistically significant effect on farm profits and small non-significant effect on cultivated area. Existing studies of this reform (Beg, 2022; Ullah and Hussain, 2023) have found positive effects of the reform on farmer productivity and land dispute resolution, in line with studies showing that digitization is a positive force for development (Muralidharan et al., 2016b; Dzansi et al., 2022). The direct effect of digitization therefore cannot explain the fall in fiscal revenues.

Instead, we show that the decrease in tax revenues is driven by a change in the bureaucrats' performance. To understand how the reform could have affected their performance, we propose a simple model capturing the main opposing forces it created. On the one hand, the introduction of technology freed up some time for bureaucrats to focus on tax collection. On the other hand, it changed their relationship with taxpayers, as reported in the survey. First, by losing responsibility over land record management, bureaucrats lost leverage over taxpayers. Before the reform, tax collectors could offer to process land permits or resolve

land disputes in exchange for tax payments. After the reform, this was no longer possible. This loss of influence could therefore lead to lower tax collection as a fraction of tax demands. Second, bureaucrats lost a lucrative source of bribes from land record management. If some of these bribes were displaced towards their tax assessment activities after the reform, then collusion between bureaucrats and taxpayers should increase, leading to lower tax demands and lower tax revenues.

We find results consistent with both of these negative forces. Firstly, bureaucrats in digitized districts reported lower cultivated areas in their tax assessments and issued lower tax demands after digitization relative to non-digitized districts. This is despite the fact that we find no significant decrease in the tax base using satellite and household survey data. Second, bureaucrats in the digitized districts collected 29.5 percentage points lower taxes as a percentage of tax demands after digitization. This corresponds to about 55% of the average tax collection performance before digitization. The proportion of bureaucrats collecting at least 50% of their target and the proportion collecting at least 75% both fell. In sum, the digitization reform both led bureaucrats to issue lower tax demands and to collect a smaller portion of these lower demands.

Our results highlight a novel channel through which digitization reforms can affect state revenues. While technology did have a positive impact on the tax base and empowered the citizens, in line with the existing literature ([Muralidharan et al., 2016b](#); [Beg, 2022](#); [Dzansi et al., 2022](#)), it also disrupted the relationship between the bureaucracy and its users, which reduced its ability to collect taxes. We find that this second effect, often overlooked in the literature, can be sufficiently strong to generate an overall decline in tax collection. These findings have important implications for the design of state capacity reforms.

First, reforms to different dimensions of state capacity cannot be studied in isolation. In our context, digitizing land rights had a negative effect on fiscal capacity because it removed existing complementarities between tasks. In other contexts, reforms could harness these existing complementarities to increase the returns on investments in state capacity. Second, investments in technology alone may not be sufficient to improve overall state capacity. Our results show that the human

and social dimensions of the bureaucracy are important and can be affected by investment in technology. Digitization reforms should therefore consider alternative means for bureaucrats to maintain social connections with citizens and the influence that comes with these connections.<sup>4</sup> They should also consider changes in human resources policies: if digitization reforms lead to corruption displacement, as in our context, then they should be accompanied by a shift in corruption monitoring or new incentive schemes.

Our results contribute to three strands of literature: the literature on digitization and development, the literature on state capacity and bureaucracies, and the literature on public finance in developing countries.

We contribute to the rapidly growing literature that examines the effects of digitization on economic development (Aker and Mbiti, 2010; Suri, 2017) by showing that digitization can have unintended consequences on state capacity. A strand of that literature has focused on the direct effect of technology on the productivity or accountability of bureaucrats (Duflo et al., 2012; Lewis-Faupel et al., 2016; Callen et al., 2020a; Dal Bó et al., 2021; Muralidharan et al., 2021; Callen et al., 2023; Deb Nath et al., 2023; Barnwal, Forthcoming; Muralidharan et al., Forthcoming). Other studies have found beneficial effects of introducing technology on tax collection. The technology studied either helped improve corporate tax filing (Okunogbe and Pouliquen, 2022), VAT records (Ali et al., 2021; Brockmeyer and Sáenz Somarriba, 2022), or customs tax (Chalendard et al., 2023), helped identifying taxpayers and welfare recipients (Muralidharan et al., 2016a), or helped tax collectors geo-locate taxpayers (Dzansi et al., 2022). Unlike other studies that find some unintended consequences of digitization on tax collection (Okunogbe and Pouliquen, 2022; Chalendard et al., 2023), the reform we studied did not have for primary objective the improvement of tax collection. Instead, it had an indirect negative effect on tax collection through the reorganization of the bureaucracy that it induced. Our work is therefore most closely related to the studies that highlight the importance of organizational or management practices in the success of technological reforms (Milgrom and Roberts, 1990; Banerjee et al., 2008). Garicano and Heaton (2010) show that the introduction of IT systems in police stations only resulted in higher

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<sup>4</sup>See Ashraf and Bandiera (2018) for a review of the importance of social connections at work.

productivity when coupled with other organizational changes such as resource allocation and management practices. Our results are consistent with a similar ‘complementarity’ hypothesis: fiscal capacity can suffer from digitization reforms if no further organizational changes are introduced.

We contribute to the literature on state capacity building (Besley and Persson, 2009, 2010; Bardhan, 2016; Besley et al., 2022) by presenting micro evidence on the negative spillover effects of an improvement in property rights on tax collection. Because the reform we study reduced the scope of the bureaucrats’ work, our paper is most closely related to studies focusing on task design, particularly multitasking in public organizations (Holmstrom and Milgrom, 1991; Dewatripont et al., 1999a; Rasul and Rogger, 2018; Chen et al., 2018). We contribute to that literature by showing that reducing the number of tasks can reduce the performance of bureaucrats. Contrary to the existing literature, we also show that changes in the scope of tasks do not just affect the relationship between bureaucrats and their supervisor (Dewatripont et al., 1999b), but also between bureaucrats and the population. Our paper therefore also contributes to understanding how the “embeddedness of the bureaucrat” – the social connections between bureaucrats and the local population – affects the functions of the state.<sup>5</sup> Together, these results contribute to a growing literature on the organizational economics of the state that highlights organization design as a determinant of state capacity (Vannutelli, 2022).<sup>6</sup>

Finally, we also contribute to the large literature on public finance in developing countries that seeks to identify the obstacles that developing countries face in collecting taxes (Besley and Persson, 2014; Gadenne and Singhal, 2014). These obstacles can include the lack of formal records (Pomeranz, 2015; Okunogbe et al., 2021; Jensen, 2022), the design of the tax code (Best et al., 2015; Brockmeyer et

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<sup>5</sup>See e.g., Evans (1995), Tsai (2007), Pepinsky et al. (2017) or Bhavnani and Lee (2018).

<sup>6</sup>Several studies show that the incentives of bureaucrats matter for public service delivery. These can be in the form of explicit incentive schemes (Khan et al., 2016, 2019), career concerns (Bertrand et al., 2020), monitoring (Callen et al., 2013), or autonomy in decision making (Rasul and Rogger, 2018; Duflo et al., 2018; Bandiera et al., 2021). Others show that the selection of bureaucrats is an important determinant of state effectiveness (Callen et al., 2020b; Barteska and Lee, 2023), where selection can be affected either at the recruitment stage (Dal Bó et al., 2013; Bai and Jia, 2016; Deserranno, 2019; Ashraf et al., 2020; Colonnelli et al., 2020; Moreira and Pérez, 2022), or through the assignment of bureaucrats across jobs or promotions (Iyer and Mani, 2012; Jia et al., 2015; Bergeron et al., 2022; Best et al., 2023; Aman-Rana, 2023).

al., 2021; Bergeron et al., Forthcoming; Basri et al., 2021), corruption (Besley and McLaren, 1993; Flatters and MacLeod, 1995; Le et al., 2020), or taxpayers' misreporting (Carrillo et al., 2017; Naritomi, 2019). Our work is most closely related to papers that highlight the incentives and the ability of tax collectors as important determinants of fiscal capacity (Khan et al., 2016, 2019; Bergeron et al., Forthcoming, 2022). We contribute to this literature by showing that introducing technology through piecemeal state capacity building can have unintended consequences for fiscal capacity because of its effect on tax collectors.

## 2 Background and data

### 2.1 Background

**Agricultural Income Tax.** We focus on the collection of a tax, the Agricultural Income Tax (AIT), which is levied on landowners in rural areas of the province of Punjab. This tax is one of the main sources of revenues to the government from agriculture. The amount of tax due is based on either the area of cultivated land or the profits of the farm. Specifically, farmers owe whichever of the cultivated area-based tax and the profit-based tax is largest ([Punjab Agricultural Income Tax Act, 1997](#), 3.4). When land is rented out by landowners to farmers, the landowner is liable for the tax ([Punjab Agricultural Income Tax Act, 1997](#), 2.1 and 3.1).

The cultivated area-based tax is progressive and ranges from 300 to 600 PKR per acre, with irrigated areas and orchards subject to a higher tax rate ([Punjab Agricultural Income Tax Act, 1997](#), 3.1). The profit-based tax is also progressive and starts with a flat amount of 1,000 PKR for the first tranche (profits between 400,000 and 800,000 PKR), progressively increasing to 300,000 PKR plus 15% of the amount of profits exceeding 48,00,000 PKR ([Punjab Agricultural Income Tax Act, 1997](#), 3.3).<sup>7</sup> In practice, due to the difficulty of measuring income, the profit-based tax is restricted to large landowners who own more than 50 acres of land, which only applies to 12% of farms ([The Agricultural Census, 2010](#)).

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<sup>7</sup>Income below 400,000 PKR is exempt.



The tax is collected by a team of local bureaucrats called *revenue officers*. Each team of revenue officers covers a jurisdiction comprising 2 to 3 villages called a *revenue circle*. In total, there are 596 bureaucrats, called *Qanungos*, who directly manage these revenue circles.<sup>8</sup> We study bureaucrats at this level of the hierarchy. The taxable amount in a fiscal year, which runs from the 1<sup>st</sup> of July to 30<sup>th</sup> of June the following year, is assessed by the same bureaucrats who collect the tax. At the start of a fiscal year, bureaucrats assess whether an agricultural land has been cultivated and note its characteristics (irrigated or not, type of crops) during crop inspections (*Girdawari*), to calculate the cultivated area-based tax. Once tax is assessed, the bureaucrats issue tax demands around November and collect taxes over the remaining course of the fiscal year.<sup>9</sup> Income-based tax is calculated using self-reported profits.<sup>10</sup>

Bureaucrats do not receive any performance-based compensation for tax assessment or tax collection. Senior officials in the revenue department are required to oversee crop inspections conducted by junior officials (the unit of analysis in this paper) and are expected to conduct random checks on a minimum of 25% of the land under their jurisdiction. In cases where a junior official is found to be underperforming, they may face a suspension.<sup>11</sup> These managers also monitor the progress of the team on tax collection. Similar disciplinary action can be taken if the official systematically fails to collect enough taxes. The bureaucrats' promotions are based on tenure in the bureaucracy according to a pre-determined schedule. However, senior officials and politicians can informally influence the timing of promotions to allow high-performing bureaucrats to be fast-tracked. As in other bureaucracies (Iyer and Mani, 2012; Khan et al., 2019), transfers of bureaucrats across different revenue circles serve as an additional means of recognizing and incentivizing performance. These mechanisms introduce some potential career incentives for bureaucrats to achieve a high performance.

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<sup>8</sup>The total revenue bureaucracy spans multiple tiers and includes approximately 6000 officials.

<sup>9</sup>Bureaucrats are expected to carry out two crop inspections: during the fall (*Kharif*) and spring (*Rabi*) cropping season. In principle, taxes should be levied separately for each cropping seasons. In practice, bureaucrats generate tax demand for the entire year based on the first cropping season to allow themselves enough time to collect taxes by the end of the fiscal year.

<sup>10</sup>Landowners must file their tax returns by the end of December for the respective fiscal year.

<sup>11</sup>A suspension does not involve a wage cut but the removal of the revenue official from the job and its associated perks.

**Digitization of land records.** In 2005, the government of Punjab began a reform of the land record management system to digitize the records with the support of the World Bank. The objective of the reform was to increase the reliability and the transparency of a system that was prone to errors and corruption. Figure B.1 and B.2 in appendix show a manual land record and its digitized version.<sup>12</sup>

The government planned to roll out the digitization program in three phases. In each phase, 10-12 districts were selected to be digitized. This staggered design was driven by the financial difficulty of rolling out a reform of this size across the whole province at once. Figure 1 shows that there were no statistically significant differences in baseline characteristics between districts digitized in the first two phases of the rollout and those digitized in the last phase.<sup>13</sup> The initial schedule was to roll out the digitized system in 2009 for phase 1, 2010 for phase 2, and 2011 for phase 3. The actual rollout was delayed and Figure 2 shows the proportion of villages that were digitized in each phase over time.

The reform had two effects. It secured property rights and it changed the type of tasks carried out by the local bureaucrats that we study.<sup>14</sup> Prior to the digitization reform, bureaucrats were responsible for recording sales or exchanges of land and properties and for issuing land titles, as well as for assessing and collecting taxes. The reform relieved them of their land record-related duties, which also affected their interactions with the local population. Overall, 69% of bureaucrats reported that the reform changed their tasks, of which 75% said that some tasks were removed but 59% indicated that some tasks were also added (see Figures B.5 and B.6 in appendix). The tasks added were mostly about record correction and additional paper work, which was part of the transition from manual to digitized land records (see Figure B.7 in appendix). Therefore, the new tasks were mostly relevant in the short-term. On net, the number of hours worked reported by the

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<sup>12</sup>Figure B.3 shows the new “Arazi Record Centers” set up to deliver services using digitized land records.

<sup>13</sup>Figure B.4 in appendix shows a similar balance test when splitting digitized districts into phase 1 and 2 districts. Phase 1 districts were statistically significantly smaller in population size and have less factories. This suggests that the government planned to start out the program in smaller less developed districts, but did not otherwise select districts in systematic ways.

<sup>14</sup>Beg (2022) shows that the reform improved the security of property rights, reduced land disputes, and resulted in the re-allocation of land to more productive farmers. Ullah and Hussain (2023) show that the reform resulted in an increase in land disputes resolution.

bureaucrats did not increase significantly. Figure 3 shows that 72% of bureaucrats reported no change in hours worked, 4% reported a decrease, and 24% reported an increase. This suggests that the majority of bureaucrats either used the time freed up from land records to work on other tasks or simply worked less after the reform. Our survey data further confirms that the net reported decrease in hours is not significantly different from the net reported increase (see Figure B.8 in appendix).

The bureaucrats also reported two interesting changes following the reform. First, they indicated that digitization negatively affected their ability to collect taxes. The main reason cited was a loss of influence over taxpayers as shown in Figure 4. Second, the bureaucrats lost an important source of bribe income. Obtaining bribes or ‘tips’ in exchange for a speedy processing of land records was common before the reform. In a survey of households carried out before the reform, 82% of respondents indicated that the way to “remedy the problems faced in accessing land records” was to give a bribe, and 65% reported that they could not access land record services without unofficial payments (Gallup, 2009). Because the bureaucrats no longer had control over the land record process, they lost this source of bribe. Only 2% of households report paying a bribe for land records once those have been digitized and a majority of households had a good or very good experience with the newly digitized services (see Figures B.9 and B.10 in appendix). Finally, the implementation report of the World Bank noted that “The majority of respondents in 65 focus group discussions mentioned that dealing with the Patwari involved huge bribes, but that these costs no longer exist under the new system.” (World Bank, 2017). The bureaucrats reported a similar decline in bribes: Figure 5 shows that 48% of bureaucrats agreed that citizens want to tip to get land titles before digitization compared to 33% after digitization.<sup>15</sup>

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<sup>15</sup>Given that admitting to this behavior reflects badly on the bureaucracy, these responses likely underestimate the true magnitude of bribery. We expect the under-reporting to be similar before or after the reform. Figure 5 supports this interpretation since the proportions of respondents that refused to answer the question on tips before and after the reform are similar. The question asked about willingness to tip in a revenue circle that has been digitized which could include both villages that have been digitized and villages that have not. This can explain the positive share of respondents reporting bribes after digitization.

## 2.2 Data sources and key variables

**Digitization rollout.** The data on digitization includes both the planned and actual rollout of the digitization reform. We obtained the planned rollout of the program from the Land Record Management Information System (LRMIS) project office in Lahore. This data indicates which districts were intended to be digitized in phase 1, 2 or 3 of the program. We obtained the actual progress of the digitization program from the Punjab Land Records Authority (PLRA) in February 2018. This data describes the digitization status of each revenue circle: whether and on which date the land records of each village in the revenue circle have been digitized.

We define a *phase* as the set of districts that were intended to be digitized at the same time as each other in the rollout plan. We consider a phase as being *digitized* in a given year if at least 5% of villages in that set of districts have been digitized by that year. We use the actual rollout of digitization to determine the start of digitization rather than the planned rollout, because the actual rollout was significantly delayed relative to the plan so no districts were actually digitized in the years planned. However, we define the beginning of the digitization at a phase level, rather than at an individual district level, to use variation in the rollout that is not driven by unobserved characteristics of the districts which could be correlated with both the pace of digitization and tax collection. Considering the entire phase to be digitized if just 5% of the villages in a phase were digitized allows us to retain the intention-to-treat interpretation of the estimates that we aim to capture.

This allows us to define our treatment variable, ‘digitization of land records’ as a dummy variable that takes value 1 in a district and year if the district belongs to a phase that has been digitized by that year. Based on this definition, the treatment years are defined as follows: Phase 1 is treated in fiscal year 2012, phase 2 in fiscal year 2013, and phase 3 in fiscal year 2014. In Appendix Table A.1, we show that our results are robust to using alternative thresholds of proportion of villages than 5% to define a phase as digitized.

**Agricultural tax collection.** We hand collected the agricultural tax collection records of the Board of Revenue (BOR), the agency in charge of tax collection,

and carried out a large-scale digitization exercise to build a unique dataset of agricultural taxation in Punjab (see Appendix C for the record room and the proforma on which this information is collected). The data contains both the total amount of taxes collected (combining cultivated area-based tax and income-based tax) and the total tax demands issued to taxpayers, at the revenue circle level. The tax demand is based on the assessment carried out by the bureaucrats and serves as the target amount of taxes for them to collect. The records have monthly information at the revenue circle level from 2006-2013 (28,572 revenue circle-months).<sup>16</sup> We aggregate the taxation data at the district-year level.<sup>17</sup> The resulting data is a balanced panel of 212 districts-fiscal years.

**Actual tax base.** To evaluate the effect of the reform on the tax base (cultivated area or farm income), we rely on three sources of data. First, we compiled satellite data on vegetation cover to measure cultivated area. We use the Normalized Difference Vegetation Index (NDVI) (see Appendix F for details), a commonly-used proxy for crop yield in developing countries (Rasmussen, 1992; Vrieling et al., 2011; Beg, 2022) which allows meaningful comparisons of year-on-year changes in vegetation growth (Huete et al., 2002). We complement the satellite data with survey data from the Pakistan Living Standards Measurement Survey (PSLM) which includes questions on agricultural land owned (in acres) and agricultural land irrigated from a repeated cross-section of households across Punjab.<sup>18</sup> We analyze data from the 2006, 2008, 2010, and 2012 waves of this survey, each wave representing approximately 40,000 land-owning citizens in rural households across Punjab. The dataset is representative at the district level. Finally, we use Household Income and Expenditure Surveys (HIES) data from Beg (2022) to investigate

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<sup>16</sup>This data is an unbalanced panel of revenue-circles and months since some of the tax files were destroyed in flooding. To ensure that the data is representative at a district level, we created inverse probability-weighted sums. For each time period, the weights are based on the number of revenue circles for which we have data, relative to the total number of revenue circles in a Tehsil and district. Due to the presence of outliers, we dropped a revenue circle-fiscal year if its annual tax demand was more than two standard deviations above its average over time. This resulted in a drop of 65 revenue circle-fiscal years out of 3,492 (1.9%) and one observation at the district-fiscal year level out of 220 (0.5%).

<sup>17</sup>We aggregate the monthly data at the year level since tax assessments are issued annually and the monthly tax collection data is therefore noisier.

<sup>18</sup>We restrict the analysis to rural households in PSLM as we are interested in agricultural outcomes.

the effects of digitization on agricultural profits,<sup>19</sup> the other possible element of the tax base. This data collects demographics, employment, expenditure, and saving information from a repeated cross-section of households from districts of Punjab. We use data from the 2005, 2007, 2011, and 2013 waves of the survey. Following the approach in Beg (2022), we focus on farm-level data provided by cultivating households (approximately 5,986 out of 15,767 rural households).

**Tax base reported by bureaucrats.** While we cannot directly observe tax demands issued by bureaucrats to each taxpayer, we can observe two aggregate measures of the tax base assessed by bureaucrats. First, we use data compiled by the Directorate of Agriculture (Economics and Marketing) of Punjab who use the cultivated area reported by the bureaucrats we study to report average cultivation across districts for 2007-2013.<sup>20</sup> Second, we use the administrative data on the assessment of tax made by the bureaucrats at the revenue circle-fiscal year level, which we aggregate at the district-fiscal year level to ensure comparability with the first measure.

**Bureaucrat career history and performance.** For the last part of our analysis, we complement the administrative tax collection data with a retrospective survey of 750 bureaucrats involved in tax collection around the time of the reform.<sup>21</sup> This survey gives us the career history of the bureaucrats across different revenue circles and their perception of the reform, its effects on tax collection, and how the reform affected their interactions with superiors and with the population. We carried out a string matching exercise to merge the tax, digitization, and bureaucrats' careers datasets as there were no unique revenue circle identifiers in any of these

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<sup>19</sup>Beg (2022) calculates profits per acre as the difference in the value of output per acre and the total expenses per acre. The value of each crop is calculated using the yield times median price for the crop across all farm households. Beg (2022) winsorized values since profits are expected to be measured with error.

<sup>20</sup>Data available at <http://www.amis.pk/Agristatistics/DistrictWise/DistrictWiseData.aspx>. There is no data available for the year 2006.

<sup>21</sup>The survey was first carried out in person in September 2020. We carried out a separate telephonic survey focusing on the bureaucrats' career histories in November 2020. Appendix D describes the details of the sampling methodology. For a random subset of the data, we confirmed the accuracy of the responses by comparing them to official records of bureaucratic transfers.

datasets.<sup>22</sup> Merging the tax and digitization data with the bureaucrats' career data allows us to identify the tax performance of a bureaucrat and whether they worked in a revenue circle that was digitized at any given point in time.<sup>23</sup> This data therefore allows us to study the bureaucrats' performance while controlling for bureaucrat-specific unobserved heterogeneity.

### 3 Did the digitization reform affect tax collection?

We now turn to testing our main question: how did the digitization reform affect tax collection?

#### 3.1 Identification strategy

There are several difficulties in measuring the effect of digitization reforms on fiscal capacity. Policy makers could introduce digitization reforms at times where bureaucracies are underperforming due to structural issues. Alternatively, some districts might be targeted for the implementation of the reform because bureaucrats in these districts face difficulties collecting taxes and need technological support in other tasks. Our differences-in-differences strategy helps us to address these concerns.

Since the actual rollout of the reform across districts could depend on time-varying district characteristics which correlate with tax collection, we exploit the *planned* rollout of the digitization reform.<sup>24</sup> Throughout the paper we present intent-to-treat analysis, which estimates the average return to "as-is" implementation of the digitization reform following the "intent" to implement the new

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<sup>22</sup>Appendix E describes how we string-matched the tax and bureaucrats' survey data to create a panel of bureaucrats-revenue circles-fiscal year and how we matched the tax and digitization data.

<sup>23</sup>If any bureaucrat held two positions in a time period, we used the position with the longer time-span and dropped the other from the sample. We dropped 5 observations for which both positions had the same duration and 1 observation in which the position was only held for 14 days.

<sup>24</sup>Figure 2 shows the cumulative proportion of villages digitized by month in each set of districts and appendix Table A.2 shows the correlation of our digitization variables with the number of villages that have been actually digitized land records. Being in a planned digitized district results in 173 more villages with digitized land records than being in a phase 3 district, indicating a strong effect of the plan on the actual rollout.

digitized system. These estimates reflect the impact of the government’s decision to digitize land records net of the logistical and political economy challenges of implementing this project in practice. This is the relevant policy parameter.<sup>25</sup>

Our strategy compares the difference in tax collection before and after digitization between districts where digitization was planned to be introduced earlier and those where it was intended to be introduced later. The identification assumption motivating this estimation strategy is that early digitized districts and later digitized districts have parallel trends: districts in phases 1 and 2 of the reform would have experienced, on average, the same changes in tax collection over time as those in phase 3, were it not for the digitization of their land records.

**Event Study.** Following the existing literature, we assess the evidence in support of the parallel trends assumption using an event-study plot prior to conducting the main analysis. Specifically, for district  $d$  and fiscal year  $t$  between 2006-2013, we estimate the following regression:

$$y_{dt} = \alpha_d + \alpha_t + \sum_{k=-6}^{k=2} \rho_k D_{k(dt)} + \epsilon_{dt} \quad (1)$$

where  $y_{dt}$  is the inverse hyperbolic sine (arcsinh) of the total tax collected in district  $d$ , during fiscal year  $t$ , that is,  $y_{dt} = \ln(\text{tax}_{dt} + \sqrt{1 + (\text{tax}_{dt})^2})$ ,  $\alpha_d$  are district fixed effects,  $\alpha_t$  are fiscal year fixed effects, and  $D_{k(dt)}$  is a set of indicator variables that takes value one if district  $d$  in fiscal year  $t$  was  $k$  years away from being digitized. The error terms are clustered at the district level as that is the level of the treatment (Abadie et al., 2023). The coefficients  $\rho_k$  estimate the effect of being treated  $k$  years before and after digitization. The omitted time period is the one right before the digitization year. A set of statistically insignificant  $\rho_k$  for all the years before treatment lends support to the parallel trends assumption.

We use the inverse hyperbolic sine (arcsinh) transformation for both the event

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<sup>25</sup>In Appendix Table A.3 we also present the results of a regression of tax collected on the number of villages digitized (with year and district fixed effects). The effects observed from digitization are comparable, though of a smaller magnitude than the intent-to-treat estimates, and statistically significant at the 5% level.



study and our main specification, because our dependent variable follows a right-skewed distribution. We are less concerned about the variable having a large probability mass at zero, another common reason for using this transformation (Chen and Roth, 2023): the proportion of observations with zeros is just 5% (11 out of 212 district-year observations). We discuss the robustness of our results to issues that can arise from using this transformation in Section 3.2.1.

Figure 6 plots  $\rho_k$  for each period  $k$  and their corresponding 95% confidence intervals.<sup>26</sup> Two-way fixed effects (TWFE) regressions have been shown to deliver consistent estimates only under relatively strong assumptions about homogeneity in treatment effects (Goodman-Bacon, 2021). We therefore also plot coefficients generated from recently-proposed estimators that are robust to treatment effect heterogeneity (Borusyak et al., 2024; Callaway and Sant’Anna, 2021; Sun and Abraham, 2021). The results presented in Figure 6 are robust to treatment effect heterogeneity and provide support to the parallel trend assumption: irrespective of the estimator used, the coefficients for the years preceding the digitization reform are near zero and do not exhibit any significant pre-trends.

## 3.2 Estimation and results

To obtain the causal effect of digitization on tax collection, we use a differences-in-differences estimation by running the following regression at the district-year level:

$$y_{dt} = \eta_d + \eta_t + \beta \text{Digitization}_{dt} + \varepsilon_{dt} \quad (2)$$

Our outcome variable,  $y_{dt}$  is the inverse hyperbolic sine (IHS) of the total tax collected in district  $d$  during fiscal year  $t$ , in thousand of Rupees. Our treatment variable,  $\text{Digitization}_{dt}$ , is a dummy that takes the value of one if a district  $d$  belongs to a phase that has been digitized by year  $t$ . Finally,  $\eta_d$  and  $\eta_t$  are district and fiscal year fixed effects, respectively. Standard errors are clustered at the district

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<sup>26</sup>Phase 1 districts were digitized in FY2012 while phase 2 districts were digitized in FY2013. Therefore, we can estimate the effects of digitization for two years after the reform (2012-2013) for districts in phase 1, but only for one year after digitization (2013) for districts in phase 2. The control districts are phase 3 districts which were digitized starting from FY2014.

level. To account for the number of clusters (36 districts), we also report *Wild* clustered bootstrapped  $p$ -values with 10,000 replications (Cameron and Miller, 2015) throughout the analysis.

Table 1 shows our main result: the digitization reform led to an 84% decrease in tax collection relative to districts that were not digitized.<sup>27</sup> Instead of increasing fiscal revenues, the modernization of state capacity therefore caused a large and statistically significant decrease in tax collection. The decrease in tax collection due to the digitization reform is substantial. Even when measured in Rupee terms, the decrease of 8,053,000 Rupees following the reform in phase 1 and 2 districts relative to phase 3 ones represents a 49% decrease relative to the mean of tax collection before digitization (see Appendix Table A.4).

The magnitudes of these effects is in line with other findings in the literature. For instance, Okunogbe and Pouliquen (2022) find that corporate tax payments decreased by 40% following the introduction of electronic filings among firms classified as presenting a lower risk of tax avoidance.<sup>28</sup> Knebelmann et al. (2023) find that the tax base for property tax is 83% lower when the assessment is carried out at the discretion of bureaucrats relative to when it follows an algorithm. The magnitude of the decrease should also be assessed in the context of the tax we study. Given that there can be a lot of variations in agricultural tax collection, the decrease of 8,053,000 Rupees represents 40% of the historical standard deviation in tax collection prior to the reform.<sup>29</sup> Finally, the decrease in tax collected can have important economic consequences. While the tax that we study is not the largest source of revenue for the government, the loss of 8,053,000 Rupees due to the reform still represents a significant shortfall. Extrapolated across all 36 districts, the amount of lost taxes could have funded cash transfers for an additional 15,428 families on the government's main social welfare program (Benazir Income Support Programme (BISP)).<sup>30</sup>

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<sup>27</sup>The percentage change is approximated as usual by  $\exp(\hat{\beta}) - 1 = \exp(-1.826) - 1 = -0.839$ .

<sup>28</sup>The decrease they measure, however, is not statistically different from zero at conventional levels. The intuition they suggest for this result is that these firms used to pay more in the physical presence of the tax collector.

<sup>29</sup>The standard deviation of our outcome variable, tax collection, across all districts between FY2006 and FY2011 is 20,124,000 Rupees.

<sup>30</sup>The annual transfer for families eligible to the BISP was 18,792 Rupees in 2015 (Cheema et al.,

This decrease in tax collection could be due to two reasons. First, the tax base (the cultivated area and the farmers' profits) could have decreased as a result of digitization. Second, digitization could have decreased the bureaucrats' capacity to collect taxes. Before turning to these mechanisms in the next section, we discuss a number of robustness tests we carried out.

### 3.2.1 Robustness

**Robustness using the “more credible approach”.** Instead of requiring that parallel trends hold exactly, we investigate the robustness of our results to alternative assumptions about differences in trends in tax collection between digitized and non-digitized districts. We follow [Rambachan and Roth \(2023\)](#) and use the “more credible approach” to parallel trends. They suggest that restrictions on the possible violations of parallel trends depend on the economic context. To determine these restrictions, we use pre-digitization data to create a linear trend that is extrapolated to post-digitization (see Appendix Figure B.11). Since the coefficients are close to the linear trend in the pre-treatment period, we impose that the differential trends evolve smoothly over time by bounding the extent to which its slope may change across consecutive periods. We therefore use the following formula suggested by [Rambachan and Roth \(2023\)](#):

$$\Delta^{SD} := \{\delta_t : |(\delta_{t+1} - \delta_t) - (\delta_t - \delta_{t-1})| \leq M, \forall t\}$$

where  $\delta_t$  refers to the difference in trends between digitized and non-digitized districts at time  $t$ .  $M$  governs the amount by which the slope of  $\delta$  can change between consecutive periods. If  $M = 0$  the difference in trends between digitized and manual districts would be exactly linear, while  $M > 0$  relaxes the assumption of exact linearity. Figure 7 shows that the main results remain robust up to a value of  $M=0.14$ . To benchmark this upper bound on the parameter  $M$ , we follow the methodology in [Dustmann et al. \(2021\)](#) and [Aman-Rana et al. \(2023b\)](#). We compare the parameter  $M$  with the absolute deviations of the coefficient  $\rho$  (see

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2016). The loss of 289,922,000 Rupees (8,053,000 Rupees multiplied by 36 districts) would therefore cover  $\frac{289,922}{18,792} = 15,428$  families.

Equation 1) from the linear trend in pre-treatment periods. The median value of that deviation is  $M=0.17$  and the 45<sup>th</sup> percentile is  $M=0.07$ . Our results therefore remain robust to a deviation from a linear trend as large as the 45<sup>th</sup> percentile of the pre-treatment deviations from the linear trend.

**Bureaucrat transfers across districts.** One might worry that the digitization reform drove bureaucrats to move out of digitized districts to non-digitized ones or vice versa. These transfers could explain the decrease in tax collection if bureaucrats that were systematically collecting less taxes were relocating to digitized districts or bureaucrats collecting more taxes to non-digitized ones. While such transfers are not allowed by law, we also verify that this was indeed the case by using our data on the bureaucrats' careers. This data confirms that only 2 out of the 118 bureaucrats have ever been posted outside the districts where they started their careers (see Figure B.12 in appendix). The situation was similar for their subordinates: only 2 out of 440 subordinates were ever transferred out of their original districts. We also rule out that transfers at higher levels in the hierarchy could have driven the results by systematically changing how these bureaucrats were managed. We show in Table A.5 in appendix that our results remain robust when controlling for the proportion of the bureaucrats' managers in each district whose ability was above median.<sup>31</sup> Together, these results indicate that such spillovers do not threaten our identification strategy.

**Anticipation effects.** Another concern is that either the bureaucrats or the citizens could have anticipated the digitization reform and changed their behavior as a result. These anticipation effects could bias our results if they systematically impact tax collection more in phases 1 and 2 districts relative to phase 3 districts. Appendix Table A.6 uses two alternative definitions of the timing of digitization as a placebo test. In Column (1) the digitization reform is defined as starting in 2006 for phase 1 districts and 2007 for phase 2 districts, while in Column (2) these

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<sup>31</sup>We measured ability using four incentivized measures. The first two were incentivized ability tests based on Hanna and Wang (2017). These included a cognitive ability matrix test and a digit span memory test. The third and fourth measures were based on their general knowledge and knowledge of rules and laws related to their jobs as revenue officials.

timings are defined as 2009 and 2010, respectively. The effects are much smaller in magnitude than the main effects in Table 1 and are not statistically significant (*Wild* clustered bootstrapped  $p$ -value is 0.79 and 0.59), suggesting that anticipation effects do not bias the results in this case.

**Treatment effect heterogeneity.** As discussed above, two-way fixed effects regressions can produce inconsistent estimates when treatment effects are heterogeneous. Figure 6 showed that the fall in tax collection following the reform is not driven by our choice of estimator. Appendix Table A.7 replicates Equation 2 using only the never-treated phase 3 districts as the control group. This avoids the  $2 \times 2$  differences-in-differences comparisons between newly treated and already treated units and gives consistent estimates even in the presence of heterogeneous treatment effects across time or treated units. The results show that the effects are of similar magnitude to Table 1 and significant at conventional levels when comparing the treatment phases separately.

**Randomization-based inference tests.** Finally, we replicate Table 1 and compute the  $p$ -values from permutation tests similar to randomization-based inference tests (Athey and Imbens, 2017; Young, 2019). This tests whether the effects of digitization are simply due to chance based on the selection of districts that were assigned to be digitized in phase 1 and 2 relative to phase 3. We re-assign digitization over districts 10,000 times and compute the estimates under the null hypothesis that the reform has no effect. We then locate the point estimates coming from our real data in the distribution of the 10,000 treatment assignment simulations. The  $p$ -value is based on the share of estimates from the 10,000 reassignments that are higher in absolute value than our point estimates in Table 1. Appendix Table A.8 reports the  $p$ -value of 0.021, increasing confidence in our main analysis.

**Intensive vs. extensive margin.** Treatment effect estimates using arcsinh transformations are sensitive to changes in the units of the outcome (De Brauw and Herskowitz, 2021; Aihounton and Henningsen, 2021). The problems identified

with log-like transformations are more prominent when there is a large probability mass at zero and the extensive margin effect is prominent (Mullahy and Norton, 2022; Chen and Roth, 2023). While the proportion of observations with zeros is just 5% (11 out of 212 district-year observations), we also present separate estimates for the extensive and intensive margin effects in Appendix Table A.4, as suggested in Chen and Roth (2023). As expected, our results are mainly driven by the intensive margin effect. The extensive margin effect is very small and statistically insignificant. We also show that our main results are comparable when running a median regression and when the outcome variable is expressed in levels in thousands of rupees.

## 4 Why did tax collection decline?

We now turn to investigating two possible channels behind the decrease in tax collection: that the tax base decreased and that the capacity of bureaucrats to collect tax decreased. Our analysis suggests that the effect is more likely to come from the bureaucrat's performance.

### 4.1 Changes in the tax base

Recall that the tax collected by bureaucrats is based on two measures: the area cultivated by farmers and the profits of the farmers, as described in Section 2. The amount of tax due is calculated based on the maximum of the tax due on cultivated area and the tax due on profit. The digitization reform could have directly impacted both of these dimensions of the tax base. On the one hand, more secure property rights could lead farmers to start cultivating plots of lands whose ownership was previously disputed or encourage landowners to rent out land to more productive farmers, thus increasing productivity and possibly farm profits (see e.g., Beg, 2022). On the other hand, more secure property rights can lead to structural change encouraging farmers to move from agriculture to other sectors, thereby reducing cultivated area. We show in this section that digitization had no significant effect on cultivated area or farmers' profits.

To show this, we use four different outcome variables: farm-level profits, the satellite vegetation cover index, a measure of whether land owned was irrigated or not, and the log of agricultural land owned.<sup>32</sup> For each measure, we estimate the effects using the same specification as Equation 2.

Table 2 shows the results. Column (1) estimates the effect of digitization on profits, while columns (2)-(4) estimate the effect on cultivated land by using the satellite vegetation cover index and the survey data on irrigation and land owned as proxies. The coefficient in column (1) shows that digitization had a positive but not statistically significant effect on profits. Columns (2) to (4) show that digitization had a small and insignificant effect on cultivated land. The positive coefficients are consistent with the findings of Beg (2022) who exploits the same reform to measure its effects on land and labor markets. Beg (2022) shows that digitization increased the productivity of farmers due to two effects: a re-allocation of land to more productive farmers and an improvement in the use of inputs and investments. Like us, she finds a positive but not statistically significant effect of the reform on farm profits.<sup>33</sup> While she finds a positive and significant effect on cultivated area per farm, she also finds that the number of households operating farms decreases, and that the increase in aggregate cultivated area is not statistically significant, which is consistent with the null effect we find on cultivated area.

Together, these results imply that digitization did not lead to a decrease in the tax base: cultivated area and profits remained unchanged as a result of it. A change in the tax base is therefore unlikely to explain the decrease in tax.

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<sup>32</sup>As described in Section 2.2 the farm-level profit data comes from a survey of farmers which is only available for 4 waves (2005, 2007, 2011 and 2013) and not yearly. We therefore need to modify our definition of the treatment year for the estimation based on this outcome: we pool phase 1 and phase 2 districts and define them as digitized for the 2013 wave while phase 3 districts remain in the control group. Similarly, data on agricultural land ownership and irrigated land from the PSLM survey is available for the 2006, 2008, 2010, and 2012 waves. In this case, we define phase 1 districts as digitized for the 2012 wave, while phase 2 and 3 districts remain in the control group.

<sup>33</sup>Beg (2022) explains the null effect on profit as the results of two conflicting effects: a re-allocation of land to more productive farmers and a decrease in average productivity from farms becoming larger.

## 4.2 Effect on performance of bureaucrats

If tax collection decreased, as shown in Section 3, but the tax base did not, as shown in Section 4.1, then the digitization reform might have reduced the bureaucrats' capacity to collect taxes. That is, the reform reduced fiscal capacity. In this section, we first propose a theoretical framework to analyse how the reform could have impacted fiscal capacity and guide our interpretation of the empirical results. We then provide evidence that the reform did decrease the tax assessment and collection by bureaucrats.

### 4.2.1 Theoretical framework

We propose a simple model of the effect of the digitization reform on the bureaucrats' capacity to collect taxes. The model captures the main opposing forces created by the reform. On the one hand, the introduction of technology freed up some time for bureaucrats to focus on tax collection. On the other hand, it disrupted their relationship with the taxpayers. Our model is informed by the survey responses of the bureaucrats. We focus on two channels through which the digitization reform disrupted their relationship with the taxpayers: a lower influence on the local population and a bribe displacement effect. Among the 46% of bureaucrats who reported that digitization made tax collection worse, 57% indicated that this was due to lower influence. Moreover, both the bureaucrats and the local population reported a substantial decrease in bribes from land record services, as noted in section 2. The model allows us to formally capture how these two channels can affect tax revenues.

**Model.** We consider a three-stage game between a bureaucrat ( $B$ ) and a farmer ( $F$ ). In the first stage, the bureaucrat assesses the amount of tax due by the farmer by visiting his farm. The bureaucrat can choose to either report the true level of tax demand observed, denoted  $\bar{T}$ , or to collude with the farmer and report a lower demand  $\hat{T} < \bar{T}$  against the payment of a bribe, denoted  $b_T$ . Let  $T \in \{\hat{T}, \bar{T}\}$  denote the amount of tax demand agreed in the first stage. In the second stage, the farmer can choose between paying his tax demand in full,  $\tau = T$  or not paying it,  $\tau = 0$ .



While the first and second stages are identical before and after the digitization reform, the third stage differs. Prior to the digitization reform, the bureaucrat decides at that stage how to allocate her time between collecting tax that is overdue (if any) and dealing with land issues for the farmer (e.g., resolving land disputes, issuing land records). Let  $h_T$  denote the proportion of time she spends collecting taxes and  $h_L$  the proportion of time she spends on land issues, with  $h_T + h_L = 1$ . Spending a proportion of time  $h_L$  on land issues gives a probability  $h_L$  of resolving these issues. If the issues are resolved, the bureaucrat receives a bribe, or ‘tip’, denoted  $b_L$ , from the farmer. If the farmer paid his tax demand in full in the second stage,  $\tau = T$ , the bureaucrat does not need to spend time collecting taxes. As a result, she can spend all her time dealing with land issues and  $h_L = 1$ .

If the farmer refused to pay his tax bill in the second stage, the bureaucrat can recover some (but not all) of the demand if she spends enough time. We assume that the bureaucrat can recover a proportion  $\frac{\tau}{T} = \lambda(h_T)^\alpha$  of the tax demand when she spends  $h_T$  of her time on tax collection. The bureaucrat cannot recover all the tax even if she spends all her time on it, so  $\lambda < 1$ , and faces diminishing returns so  $\alpha \in (0, 1)$ . We assume for simplicity that the bribe on land issues,  $b_L$ , is determined exogenously (e.g., determined by norms or capped by the budget constraint of the farmer), but the amount of bribe on tax assessment,  $b_T$ , is determined through bargaining between the bureaucrat and the taxpayer.

After the digitization reform, the bureaucrat can no longer deal with land issues. We therefore capture the digitization reform by imposing that, after the reform,  $h_L = 0$  and  $b_L = 0$  in the third stage.

The bureaucrat receives a reward, normalized to 1 proportional to the percentage of the tax demand she recovers,  $\frac{\tau}{T}$ . This captures her career concerns incentives to perform well on the job. She also values receiving bribes  $b_T$  and  $b_L$ , but faces a cost of collecting bribes that is increasing and convex in the total amount of bribes she receives. We assume that this cost is equal to  $(b_T + b_L)^2$ . Finally, the bureaucrat can get caught if she misreports the tax demand owed by the farmer. The bureaucrat therefore faces a cost  $C(\bar{T} - \hat{T})$  of reporting  $\hat{T} < \bar{T}$  with  $C(\cdot)$  increasing and convex and such that  $\lim_{\hat{T} \rightarrow \bar{T}} C'(\bar{T} - \hat{T}) = 0$  and  $\lim_{\hat{T} \rightarrow 0} C'(\bar{T} - \hat{T}) = +\infty$ . The

bureaucrat's utility is therefore:

$$\begin{aligned}
U_B(h_T, h_L, b_T, T) = & \underbrace{\lambda(h_T)^\alpha}_{\text{Career reward}} + \underbrace{h_L(b_T + b_L - (b_T + b_L)^2)}_{\text{Net benefit of bribes if land issue resolved}} \\
& + \underbrace{(1 - h_L)(b_T - b_T^2)}_{\text{Net benefit of bribes if land issue unresolved}} \\
& - \underbrace{C(\bar{T} - \hat{T})}_{\text{Cost of misreporting tax assessment}} \tag{3}
\end{aligned}$$

The farmer values his income, denoted  $w$ , net of taxes and of bribes. He also faces a cost  $L$  of facing an unresolved land issue. His utility is therefore:

$$U_F(b_T, T, \tau) = w - b_T - \tau - (1 - h_L)L - h_L b_L \tag{4}$$

**Analysis.** We relegate the formal analysis of the model to the appendix and present here the main theoretical predictions and their intuition.

We begin with the pre-reform solution. In the last stage, if the farmer has not paid his tax in full ( $\tau = 0$ ), the bureaucrat weighs the marginal benefit of collecting more taxes (due to career concerns) and that of collecting more bribes on land issues and optimally allocates an interior proportion of her time on each task:  $h_T^* = \left( \frac{\alpha\lambda}{b_L(1-2b_T)-b_L^2} \right)^{\frac{1}{1-\alpha}}$  and  $h_L^* = 1 - h_T^*$ . In the second stage, the farmer faces the following trade-off. If he refuses to pay his tax in full, he will face a lower overall tax bill as the bureaucrat will not recover the entire amount:  $\lambda(h_T^*)^\alpha T < T$ . On the other hand, the bureaucrat will need to allocate time to recovering this tax and will therefore spend less time resolving the farmer's land issues:  $h_L^* < 1$ . The farmer therefore pays his tax demand in full in the second stage if resolving the land issue is sufficiently valuable:

$$L \geq b_L + T \left[ \frac{1}{h_T^*} - \frac{\lambda}{(h_T^*)^{(1-\alpha)}} \right] \tag{5}$$

Condition 5 captures the *influence*, or leverage, that bureaucrats can exert on taxpayers when they are in charge of both tax collection and land records. If the

farmer puts a sufficiently high value on the resolution of land issues ( $L$  large), he feels compelled to pay his tax demand promptly,  $\tau = T$ , so that the bureaucrat dedicates enough time to resolving the land issue ( $h_L = 1$ ). After the digitization reform, the bureaucrat loses this leverage. The farmer anticipates that the bureaucrat will not allocate any time to resolving land issues,  $h_L = 0$  so there is no benefit to paying her tax demand in full. Doing so increases her tax payment from  $\lambda T$  to  $T$  and does not have any benefits for land issues. After the digitization reform, the farmer therefore always refuses to pay her tax demand in full in stage 2. Let  $\bar{L}(T) = b_L + T \left[ \frac{1}{h_T^*} - \frac{\lambda}{(h_T^*)^{(1-a)}} \right]$  denote the right-hand side of inequality (5). We obtain the following implication:<sup>34</sup>

**Proposition 1.** *If resolving land issues is sufficiently valuable to the farmer,  $L \geq \bar{L}(\bar{T})$ , the digitization reform should lead to lower tax collection as a percentage of tax demand:*

$$\frac{\tau_{Digital}}{T_{Digital}} - \frac{\tau_{Manual}}{T_{Manual}} = \lambda - 1 < 0$$

We now turn to the effect of the reform on the assessment of the tax demand. Suppose that the land issue is sufficiently important that the bureaucrat has some leverage over the farmer,  $L \geq \bar{L}(\bar{T})$ . Following Proposition 1, the farmer pays his tax demand in full, so a decrease in tax demand,  $T$ , translates directly in a lower tax payment. The farmer thus accepts to pay a bribe at most equal to the reduction in tax demand. Given this constraint, the bureaucrat chooses the optimal level of tax demand and bribes. The bureaucrat faces the following trade-off: lowering the tax demand allows her to extract a larger bribe, but comes at two costs: first it increases the potential punishment  $C(\bar{T} - \hat{T})$  for misreporting. Second, it increases the potential punishment for taking bribes which is equal to  $(b_L + b_T)^2$ .

The digitization reform does not affect the first cost. The potential punishment for misreporting is still present. However, it affects the second: because the

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<sup>34</sup>One assumption driving this result is that the bureaucrat cannot be as efficient at recovering taxes than when the taxpayer voluntarily pays his full tax demand. While it is captured in a reduced form in the model by assuming that  $\lambda < 1$ , more realistic modelling choices would also generate this result. For instance, the bureaucrat may have other tasks than the two considered here, so that  $h_T < 1$  even after the reform, or the bureaucrat may face a convex cost of working so that choosing  $h_T = 1$  is never optimal. Finally, she may have to allocate her effort across different farmers so that she cannot allocate  $h_T = 1$  on all farms.

bureaucrat no longer collects bribes from land record, the marginal cost of taking a bribe for a lower tax demand decreases. As a result, the bureaucrat’s willingness to accept a bribe against a lower assessment of the tax demand increases. This mechanism captures a *bribe displacement effect*: as the bureaucrat loses a valuable source of bribe from dealing with land issues, she displaces some of these bribes onto her tax activities, which translates into a lower assessment of the tax demand. We therefore obtain the following results:<sup>35</sup>

**Proposition 2.** *If resolving land issues is sufficiently valuable to the farmer,  $L \geq \bar{L}(\bar{T})$ , and the bribes obtained on land issues are large enough,  $b_L \geq \bar{b}$ , then the digitization reform should lead to a lower assessment of the tax demand:  $T_{Digital} < T_{Manual}$ .*

Our model therefore generates two empirical predictions about the effect of the digitization reform. First, the reform should lead to a lower assessment of the tax demand due to bribe displacement. Second, the reform should lead to lower tax collection due to a loss of leverage of the bureaucrat on the farmer.

#### 4.2.2 Changes in tax assessment

Bureaucrats determine the size of the cultivated area and its characteristics (irrigation, type of crops) during their crop inspection in fall. This assessment is then used to determine the tax demands that are issued to farmers. The model shows that if bureaucrats replaced the bribes they used to obtain from land records by bribes obtained from colluding with taxpayers on tax assessment, we should expect this assessment to fall. The resulting fall in tax demand could explain why tax collected decreased following the reform.

To investigate whether this was the case, we use two sets of data: data from the Directorate of Agriculture which records district-level cultivated areas based

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<sup>35</sup>The main assumption driving the displacement effect is that the bureaucrat faces a cost of taking bribes (a potential punishment) which is convex in the total amount of bribes obtained across different activities. The same logic would apply if the bureaucrat faced separate costs across different sources of bribes but had a concave utility over money. The displacement effect is partially offset by a second effect: because the reform leads the bureaucrat to collect a lower fraction of tax demands, it is relatively less valuable for farmers to decrease their tax demand. The farmer is therefore less willing to pay bribes for a lower tax assessment. The bribe displacement effect outweighs this second effect if bribes on land issues are sufficiently large .

on reports provided by the bureaucrats we study, and administrative data on tax demands issued by these bureaucrats to taxpayers, aggregated at the district level.<sup>36</sup> For each measure, we estimate the effects using the same specification as in Equation 2.

Table 3 shows the results: after the digitization reform, districts with digitized land records had 10% lower reported cultivated areas (Column 1), as well as 45% lower tax demands (which includes both cultivated-area based tax and profit-based tax, see Column 2), relative to districts with manual land records.<sup>37</sup> This is despite the fact the vegetation cover index, the farmers' profits, and the agricultural land irrigated or owned did not decrease significantly, as shown in Column (2)-(4) of Table 2. These results indicate that the digitization reform led bureaucrats to under-report the tax base and reduced the tax demands issued to farmers.

These results are consistent with the digitization reform increasing collusion between bureaucrats and taxpayers as captured by the model and with results from our survey of the bureaucrats and household surveys indicating an important drop in bribes from land record services as discussed in Section 2 (see Figure 5 and Appendix Figures B.9 and B.10). The digitization reform could have therefore led bureaucrats to try and make up for this lost income by increasing collusion on tax assessment. This is in line with other instances of 'bribe displacement' found in other contexts. (Yang, 2008; Sequeira, 2011, 2016; Dávid-Barrett and Fazekas, 2020).<sup>38</sup>

The decrease in the *reported* tax base and the corresponding lower tax demand can explain part of the decrease in tax income shown in Table 1. However, we show in the next subsection that tax collection decreased even relative to this reduced

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<sup>36</sup>We observe this data at the revenue circle level in the tax records and not at the taxpayer level. For consistency with the previous analysis we also aggregate this data at the district level.

<sup>37</sup>These effects are approximated using the transformations  $\exp(-0.106) - 1 = -0.10$  and  $\exp(-0.600) - 1 = -0.45$  respectively, as we did for the main result in Table 1

<sup>38</sup>An alternative explanation would be that the split of the bureaucracy into two separate entities (the bureaucrats we study and the new digitized centres) lead both entities to increase the amount of bribes they take because of a failure to internalize the effect of their bribe-taking behavior on the other agency (Shleifer and Vishny, 1993). While this would also lead to an increase in bribe taking, and therefore lower assessments, for the tax assessors, it should also lead to higher bribes for the bureaucrats serving the digitized centres. Appendix Figures B.9 and B.10 suggest that this is unlikely: households reported a high level of satisfaction with this new agency and only 2% reported paying bribes to these agents.

tax demand. Collusion between bureaucrats and taxpayers in assessing cultivated areas can therefore not explain all of the decrease in tax collection.

### 4.2.3 Change in performance relative to tax demand

In addition to the decrease in the reported tax base and the associated tax demand, it is possible that the digitization reform led bureaucrats to *collect* less tax. Our model suggests that this can happen when farmers put a sufficiently high value on resolving land issues (e.g. obtaining land titles or resolving land disputes). When bureaucrats are in charge of land issues, they have some leverage over farmers and can use it to encourage them to pay their tax bill. Following the digitization reform, they lose this leverage. We investigate whether tax collection performance declined by looking at four different measures.

First, we look at the effect of the digitization reform on the tax collected by bureaucrats as a percentage of the tax demands they need to collect. The tax demands issued by bureaucrats is the target that bureaucrats are expected to collect by their superiors.<sup>39</sup> We confirm this measure with two alternative variables: whether bureaucrats achieved at least 50% of their targets, and whether they achieved at least 75% of their target. These binary variables allow us to confirm that the results from the continuous measure are not driven by outliers. Finally, we also analyze whether the reform affected the bottom-end of the performance distribution by looking at the share of months per year in which the bureaucrats collected no taxes at all.

Combining the bureaucrat survey data with tax collection records allows us to carry out the analysis at the individual bureaucrat level instead of the district level analysis in the previous section. We therefore, use the within-bureaucrat variation in tax collection and run the following regression:

$$y_{idt} = \theta_i + \theta_t + \psi \text{Digitization}_{dt} + u_{idt} \quad (6)$$

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<sup>39</sup>Since the bureaucrat's objective is to collect the tax due, it is not possible for bureaucrats to over perform based on our measure of performance: once the tax due is collected, bureaucrats cannot collect more tax from that farmer.

where  $y_{idt}$  is one of the measures described above for bureaucrat  $i$  in district  $d$  and year  $t$ ,  $Digitization_{dt}$  is a dummy that takes value 1 if district  $d$  was digitized in year  $t$ ,  $\theta_i$  are bureaucrat fixed effects and  $\theta_t$  are fiscal year fixed effects. Standard errors are clustered at the district level.

Table 4 shows the results. Column (1) shows that the digitization reform led to a substantial decrease in the bureaucrat's performance. Bureaucrats in digitized districts collected almost 30 percentage points less of their collection target after digitization, relative to non-digitized districts (56% of control mean, *Wild* clustered bootstrapped  $p$ -value $<0.05$ ). We can exclude the possibility that this is due to the denominator increasing since Table 2 shows that tax demands decreased, if anything, as a result of the digitization reform. In other words, tax collection decreased even more than the tax demands did, implying that the capacity of bureaucrats to collect taxes went down.

One could worry that this is driven by bureaucrats whose tax collection dropped completely, given that the percentage of tax demand collected was quite low, even before digitization.<sup>40</sup> However, columns (2) and (3) show that the digitization reform also affected the ability of bureaucrat to achieve higher levels of tax demands: bureaucrats were 34 percentage points less likely to collect at least 50% of the tax demands in their area, and 39 percentage points less likely to collect at least 75% of these tax demands (*Wild* clustered bootstrapped  $p$ -values $<0.05$ ). Finally, column (4) shows that digitization also affected the bottom of the performance distribution: the share of months in which no tax was collected at all increased in digitized districts after the reform, although the effect is not statistically significant.

These results are consistent with the digitization reform reducing the leverage that bureaucrats had over taxpayers as captured by the model. Before the reform, bureaucrats had influence over the taxpayers' decision to pay taxes because they could allocate less time to land issues if taxes were not paid in full. After the reform, bureaucrats lost this source of influence and their capacity to collect taxes decreased. Further results from our survey of the bureaucrats also support this type of mechanism. Bureaucrats reported an important decline in their interactions

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<sup>40</sup>The mean tax collection as a fraction of the target in districts with manual land records is 54%.

with politicians (see Figure B.13 in appendix). In our context, politicians are often large landowners and would therefore benefit from the bureaucrat's help with resolving land issues (Javid, 2011). Following the reform, these politicians no longer needed to interact with bureaucrats as often if these bureaucrats could not help them resolve land issues. Politicians could help bureaucrats collect taxes but bureaucrats reported that they were less likely to do so following the reform (see Figures B.14 and B.15 in appendix). Within our model, we can interpret this type of exchange of favor as a form of influence that bureaucrats lost as a result of the reform. Before the reform, they could promise to help politicians with their land issues in exchange for help collecting taxes from farmers. After the reform, bureaucrats lost this leverage and no longer received help with their tax collection.

The decline in bureaucrats' performance, together with the analysis of the tax base presented in Section 4.1, indicate that the responsibility for the decrease in fiscal revenues lies with the bureaucrats' capacity to collect tax rather than changes in the tax base. This decrease in performance can be attributed to both under-reporting of the tax base and lower tax collection relative to tax demands.

### 4.3 Discussion

In this section, we discuss other channels through which the digitization reform could have affected bureaucratic performance in tax collection.

**Temporary disruptions in bureaucrats' tasks.** The bureaucrats were required to support the reform by helping correct records that had been digitized when necessary. Indeed, 59% of bureaucrats reported that some tasks were added as a result of the reform (see Figure B.5 in appendix). Of those, 60% reported that they were expected to correct records for digitized centers (see Figure B.7 in appendix). If these record corrections distracted bureaucrats from collecting taxes, this disruption could partly explain the decrease in collection. However, this channel seems unlikely to explain the large fall in tax collection that we observe for two reasons. First, Figure 3 illustrates that 72% of bureaucrats did not report any change in hours worked. Among the remaining, 24% reported a net increase



in hours worked, while 4% reported a net decrease. We also find that, while the average number of hours added following the reform is slightly higher than the average number of hours removed following the reform, the difference between the two is relatively small (not statistically significant at the 5% level), corresponding to about 30 minutes a day spent on new tasks (see Figure B.8 in appendix). Even if the time spent on new tasks were taken away from tax collection, 24% of bureaucrats re-allocating 30 minutes of their time per day would be unlikely to explain the large decline we observe.<sup>41</sup> Second, Figure 4 shows that, of the 46% of bureaucrats who reported that digitization made tax collection worse, only 2% indicated that this was due to additional tasks.

We also confirm that the disruptions are not simply short-run ‘teething problems’. Our main specification only allows us to see the effect up to two years after the reform since phase 3 districts become digitized two years after phase 1 districts. To investigate longer-run effects, we exploit the actual, rather than planned, variation in digitization of land records across revenue circles. While the actual rollout might be correlated with unobserved time-varying characteristics of the revenue circles, this approach allows us to measure the relationship between digitization and tax collection for up to four years after the reform.<sup>42</sup> In Appendix Figure B.16 we show an event study plot based on a specification similar to equation 1 but estimated at the revenue-circle level defining digitization based on actual rather than planned rollout. The plot shows that the negative effects of digitization of land records on tax collection persisted for four years after the reform.

**Changes to information available to bureaucrats.** The reform could have affected the information available to bureaucrats in two ways. First, the reform could have led bureaucrats to lose access to information on land records, which might be necessary to determine the owner of a plot of land. Without this information, bureaucrats might be unable to issue tax demands to the right taxpayer, which

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<sup>41</sup>The survey answers do not indicate whether the extra time spent on new tasks came at the expense of existing tasks or in the form of extra time.

<sup>42</sup>Table A.9 in Appendix shows that the endogeneity issues with this approach lead to an underestimate of the magnitude of the effect of digitization. Therefore the effect we find in the plot are likely to be lower bounds on the effect of digitization.

in turn could reduce tax demands and tax collection. Qualitative interviews with the bureaucrats reveal that this was not the case. After the reform, bureaucrats could easily access the latest land records from the digitized record centers. These records helped them to continue to carry out crop inspections and subsequent tax related activities. Second, if the reform reduced interactions between the bureaucrats and taxpayers, bureaucrats could have lost information about the ability of different farmers to pay their tax. Existing studies (Dzansi et al., 2022; Balan et al., 2022) show that tax collectors can use this information to better allocate their tax collection effort. While we cannot completely rule out this possibility, we note that the bureaucrats still frequently interacted with the local population after the reform: besides carrying out two crops inspection per year they are also active community members (Aman-Rana et al., 2023a). These interactions allow them to easily obtain information about the farmers' ability to pay.

**Changes in monitoring of bureaucrats.** The reform could have affected the way supervisors monitored the bureaucrats which, in turn, would have affected their incentives. This would be in line with theoretical explanations of multitasking problems such as Dewatripont et al. (1999a). While we cannot rule out that the reform led supervisors to change the type of information they used to assess the bureaucrats' performance, we note that there was no change in the incentive or monitoring structure of the bureaucrats. Moreover, Table A.5 in appendix shows that results remain robust to controlling for the proportion of the bureaucrats' managers in each district whose ability was above median and bureaucrats did not report significant changes in their interactions with supervisors following the reform (see Figure B.13 in appendix).

**Sabotage by influential taxpayers.** If taxpayers were against the reform, they could have attempted to stop it through active sabotage. Refusing to pay taxes could serve as a way to express their discontent with the new system and explain the fall in fiscal revenues. However, the satisfaction with the new system was high among both small and large farmers: 69% of them reported a good or very good experience with the new bureaucracy (see Figure B.10 in appendix).

## 5 Conclusion

Building strong state capacity is a prerequisite for sustainable economic development. However, state capacity is not simply the sum of the technologies and processes that governments invest in. The capacity of states to raise taxes and protect property rights also depends on the behavior of state officials.

We show that reforms introducing technology to improve the effectiveness of bureaucracies can have unintended consequences by disrupting the relationship between bureaucrats and taxpayers. Despite the positive effect of digitization on property rights and agricultural productivity, we find that the collection of agricultural tax decreased as a result of the reform. Because the reform affected the organization of the bureaucracy and changed the interactions between local bureaucrats and citizens our results highlight the need to consider informal social relationships as key dimensions of state capacity ([Besley and Dray, 2022](#); [Best et al., 2023](#)).

Our results also have important implications for the design of state capacity reforms. These reforms should be accompanied by appropriate changes to the incentives of bureaucrats, pay close attention to complementarities between different forms of state capacity and whether the reform enhances or reduces these complementarities, and find ways to replace interactions with the local population that might be removed by the introduction of technology.

## A Appendix: Proofs of theoretical results in the text

We solve the model by backward induction starting from the third stage. We first prove Lemma 1 below to obtain the bureaucrat's optimal allocation of time between land issues and tax collection in the final stage. We then solve for the decision of the farmer to pay his taxes in full in the second stage. Finally, we solve for the tax assessment offered by the bureaucrat to the farmer against some possible bribe. We first solve the model before the digitization reform, where the bureaucrat can allocate time to managing land issues. We then solve the model after the digitization reform when the bureaucrat is only in charge of collecting taxes. Finally, we compare the tax demand and collection across the two cases.

### A.1 Before the digitization reform

#### A.1.1 Stage 3

The following Lemma characterizes the bureaucrat's best-response in stage 3:

**Lemma 1.** *If  $\tau = T$  in the second stage, then  $h_T^* = 0$  and  $h_L^* = 1$ . Suppose instead that  $\tau = 0$  in the second stage, then:*

- *If  $1 > 2b_T + b_L$  and  $\alpha\lambda < b_L(1 - 2b_T) - b_L^2$ , then  $h_T^* = h_L^* = \left(\frac{\alpha\lambda}{b_L(1-2b_T)-b_L^2}\right)^{\frac{1}{1-\alpha}}$  and  $h_L^* = 1 - \left(\frac{\alpha\lambda}{b_L(1-2b_T)-b_L^2}\right)^{\frac{1}{1-\alpha}}$ .*
- *If  $1 \leq 2b_T + b_L$  or if  $\alpha\lambda > b_L(1 - 2b_T) - b_L^2$  then  $h_T = 1$ .*

*Proof of Lemma 1.* In the final stage, if the farmer paid his tax in full in the previous stage, then the bureaucrat does not need to allocate time to collecting taxes. Therefore  $h_T^* = 0$  and  $h_L^* = 1$ . If the farmer did not pay his tax in full, the bureaucrat solves the following problem: given some tax demand  $T$ , the bureaucrat chooses  $h_T$  and  $h_L$  to solve:

$$\begin{aligned} \max_{h_T, h_L} \quad & \lambda(h_T)^\alpha + h_L \times (b_T + b_L - (b_T + b_L)^2) + (1 - h_L)(b_T - b_T^2) - C(\bar{T} - \hat{T}) \\ \text{s.t.} \quad & h_T + h_L \leq 1 \end{aligned}$$

Setting the constraint to equality and substituting it in the objective function gives:

$$\max_{h_T, h_L} \lambda(h_T)^\alpha + (1 - h_T) \times (b_T + b_L - (b_T + b_L)^2) + h_T(b_T - b_T^2) - C(\bar{T} - \hat{T})$$

The first-order condition is:

$$\alpha\lambda(h_T)^{\alpha-1} - (b_T + b_L - (b_T + b_L)^2) + b_T - b_T^2 = 0$$

The second-order condition is satisfied since:  $\alpha(\alpha - 1)\lambda(h_T)^{\alpha-2} < 0$  for  $\alpha < 1$ . The first-order condition gives the following solution:

$$h_T^* = \left( \frac{\alpha\lambda}{b_L(1 - 2b_T) - b_L^2} \right)^{\frac{1}{1-\alpha}}$$

and therefore  $h_L^* = 1 - h_T^* = 1 - \left( \frac{\alpha\lambda}{b_L(1 - 2b_T) - b_L^2} \right)^{\frac{1}{1-\alpha}}$ . This solution is interior as long as  $b_L(1 - 2b_T) - b_L^2 > 0 \Leftrightarrow 1 > 2b_T + b_L$  and  $\alpha\lambda < b_L(1 - 2b_T) - b_L^2$ . If the first condition is violated, then the objective function is increasing everywhere in  $h_T$  so it is optimal to set  $h_T = 1$ . If the second condition is violated, then the optimal level of  $h_T$  is above 1 so again  $h_T = 1$ . We can never have  $h_T = 0$  since the marginal benefit of increasing  $h_T$  at  $h_T = 0$  is infinite.  $\square$

### A.1.2 Stage 2

In stage 2, the farmer anticipates how many hours the bureaucrat will spend on collecting taxes in the last stage and decides whether to pay his taxes in full accordingly. This decision is characterized in the following Lemma:

**Lemma 2.** *Given a level of tax assessment  $T$  agreed in the first stage, there exists a threshold  $\bar{L}(T)$  such that the farmer pays his tax demand in full,  $\tau = T$  if and only if  $L > \bar{L}(T)$ .*

*Proof of Lemma 2.* The expected utility of the farmer from paying his tax in full is:

$$U_F(\tau = T) = w - b_T - T - b_L$$

The expected utility of the farmer from not paying his tax bill in stage 2 is:

$$U_F(\tau = 0) = w - b_T - \lambda(h_T^*)^\alpha T - h_T^*(L - b_L) - b_L$$

Therefore, the farmer pays his tax in full if:

$$\begin{aligned} w - b_T - T - b_L &\geq w - b_T - \lambda(h_T^*)^\alpha T - h_T^*(L - b_L) - b_L \\ \Leftrightarrow h_T^*(L - b_L) &\geq T - \lambda(h_T^*)^\alpha T \\ \Leftrightarrow L &\geq b_L + T \left[ \frac{1}{h_T^*} - \frac{\lambda}{(h_T^*)^{1-\alpha}} \right] \end{aligned}$$

Therefore, defining  $\bar{L}(T) = b_L + T \left[ \frac{1}{h_T^*} - \frac{\lambda}{(h_T^*)^{1-\alpha}} \right]$  gives the result.  $\square$

### A.1.3 Stage 1

In stage 1, the bureaucrat anticipates that the farmer will pay his tax in full if and only if  $L \geq \bar{L}(T)$  and chooses  $T$  and  $b_T$  to maximize her own expected utility subject to the farmer accepting to pay the bribe.

**Lemma 3.** *Suppose that  $L \geq \bar{L}(\bar{T})$ , then the bureaucrat offers to take a bribe  $b_T^M$  such that  $c(b_T^M) + 2b_T^M = 1 - 2b_L$  to reduce the tax assessment to  $\hat{T} = \bar{T} - b_T^M < \bar{T}$ .*

*Proof of Lemma 3.* Given that  $L \geq \bar{L}(\bar{T})$ , then for any  $T$  that the bureaucrat and farmer negotiate in the first stage, the farmer pays his tax in full in the second stage,  $\tau = T$  since  $\bar{L}(\bar{T}) \geq \bar{L}(T)$  for any  $T \in [0, \bar{T}]$ .<sup>43</sup> As a result, the bureaucrat spends all her time on land issues in the third stage,  $h_L^* = 1$  and  $h_T^* = 0$ . In the first

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<sup>43</sup>The condition  $L \geq \bar{L}(\bar{T})$  is sufficient but not necessary. If it is not satisfied, then the bureaucrat would consider the possibility that if they do not reduce the assessment by a large enough amount, then the farmer might prefer to not pay his tax in full in the second stage. The bureaucrat would choose the optimal bribe and assessment in that case, given that the farmer does not pay his full tax bill and given the bureaucrat's optimal time spent on tax collection. Finally the bureaucrat would compare the expected utility from that outcome to the expected utility from the lower tax assessment which induces the farmer to pay her tax bill in full.

stage, the bureaucrat therefore solves the following problem:

$$\begin{aligned} \max_{T, b_T} \quad & U_B(h_T, h_L, b_T, T) = 1 + (b_T + b_L - (b_T + b_L)^2) - C(\bar{T} - T) \\ \text{s.t.} \quad & w - b_T - T - b_L \geq w - \bar{T} - b_L \end{aligned}$$

The bureaucrat should set the bribe such that the farmer's constraint binds:  $\bar{T} - T = b_T$ , otherwise she could increase  $T$  to decrease the cost of misreporting while keeping the bribe constant. Substituting into the maximization problem:

$$\max_{b_T} b_T + b_L - (b_T + b_L)^2 - C(b_T)$$

Taking first-order condition gives:  $1 - 2(b_T + b_L) - c(b_T) = 0 \Rightarrow c(b_T) + 2b_T = 1 - 2b_L$ . The second-order condition is satisfied since:  $-2 - c'(b_T) < 0$ . Therefore, the bureaucrat sets  $b_T = b_T^*$  such that  $c(b_T^*) + 2b_T^* = 1 - 2b_L$  and  $\hat{T} = \bar{T} - b_T^*$ .  $\square$

## A.2 After the digitization reform

After the digitization reform, the bureaucrat cannot work on any land-related issues, so  $h_T = 1$  in the third stage. Anticipating that  $h_T = 1$ , the farmer prefers not to pay his tax in stage 2:

**Lemma 4.** *After the digitization reform, the farmer chooses  $\tau = 0$  in the second stage.*

*Proof of Lemma 4.* This follows directly from comparing the farmer's utilities:  $w - b_T - T < w - b_T - \lambda(1)^\alpha T \Leftrightarrow \lambda < 1$ .  $\square$

In the first stage, the bureaucrat's combination of misreporting and bribe is:

**Lemma 5.** *After the digitization reform, the bureaucrat offers to take a bribe  $b_T^D$  such that  $\frac{1}{\lambda}c\left(\frac{b_T^D}{\lambda}\right) + 2b_T^D = 1$  to reduce the tax assessment to  $\hat{T} = \bar{T} - b_T^D < \bar{T}$ .*

*Proof of Lemma 5.* Given that the farmer never pays his tax in full in the second stage,  $\tau = 0$  and the bureaucrat spends all her time on tax issues in the third stage,

$h_T^* = 1$ , the bureaucrat solves the following problem:

$$\begin{aligned} \max_{T, b_T} \quad & U_B(h_T, h_L, b_T, T) = \lambda + (b_T - (b_T)^2) - C(\bar{T} - T) \\ \text{s.t.} \quad & w - b_T - \lambda T \geq w - \lambda \bar{T} \end{aligned}$$

The bureaucrat should set the bribe such that the farmer's constraint binds:  $\lambda(\bar{T} - T) = b_T$ , otherwise she could increase  $T$  to decrease the cost of misreporting while keeping the bribe constant. Substituting into the maximization problem:

$$\max_{b_T} b_T - (b_T)^2 - C\left(\frac{b_T}{\lambda}\right)$$

Taking first-order condition gives:  $1 - 2b_T - \frac{1}{\lambda}c\left(\frac{b_T}{\lambda}\right) = 0 \Rightarrow \frac{1}{\lambda}c\left(\frac{b_T}{\lambda}\right) + 2b_T = 1$ . The second-order condition is satisfied since:  $-2 - \frac{1}{\lambda}c'\left(\frac{b_T}{\lambda}\right) < 0$ . Therefore, the bureaucrat sets  $b_T = b_T^D$  such that  $\frac{1}{\lambda}c\left(\frac{b_T}{\lambda}\right) + 2b_T = 1$  and  $\hat{T} = \bar{T} - b_T^*$ .

□

### A.3 Change in tax collection and assessments due to the reform

We can now turn to the proof of Propositions 1 and 2.

*Proof of Proposition 1.* From Lemma 2, we know that, in equilibrium, the farmer pays her tax in full in stage 2 if  $L \geq \bar{L}$  before the reform. The tax collection as a percentage of tax demand before the reform is therefore:  $\frac{\tau^{Manual}}{T^{Manual}} = 1$ . From Lemma 4, we know that, in equilibrium the farmer never pays his tax in full in stage 2 before the reform. By definition, the bureaucrat spends all her time collecting taxes after the reform, so  $h_T^* = 1$ . Therefore, the tax collection as a percentage of tax demand after the reform is:  $\frac{\tau^{Digital}}{T^{Digital}} = \lambda(h_T^*)^\alpha = \lambda$ . We can therefore conclude that, if  $L \geq \bar{L}$ , then

$$\frac{\tau^{Digital}}{T^{Digital}} - \frac{\tau^{Manual}}{T^{Manual}} = \lambda - 1 < 0$$

□



*Proof of Proposition 2.* From Lemma 3, we know that the equilibrium tax assessment before the reform is  $\hat{T}^{Manual} = \bar{T} - b_T^M$  with  $b_T^M$  such that  $c(b_T^M) + 2b_T^M = 1 - 2b_L$ . From Lemma 5, we know that the equilibrium tax assessment after the reform is  $\hat{T}^{Digital} = \bar{T} - b_T^D$  with  $b_T^D$  such that  $\frac{1}{\lambda}c(\frac{b_T^D}{\lambda}) + 2b_T^D = 1$ . Therefore, tax assessment is lower after the reform if and only if:  $b_T^M < b_T^D$ . We next show the following result:

**Lemma 6.** *There exists  $\bar{b}_L$  such that  $b_T^M < b_T^D$  if and only if  $b_L > \bar{b}_L$ .*

*Proof of Lemma 6.* Let  $\Delta(b_L) = b_T^M(b_L) - b_T^D$ . First note that since  $b_T^M$  solves  $c(b_T^M) + 2b_T^M = 1 - 2b_L$  and the left-hand side of that condition is increasing and continuous given that  $C(\cdot)$  is increasing, continuous, and convex. Therefore, the equilibrium  $b_T^M$  is strictly continuously decreasing in  $b_L$ . In addition, since  $b_T^D$ , which solves  $\frac{1}{\lambda}c(\frac{b_T^D}{\lambda}) + 2b_T^D = 1$ , is independent of  $b_L$ , we can conclude that  $\Delta(b_L)$  is continuously decreasing in  $b_L$ . Next, note that the function:  $LHS(\lambda) = \frac{1}{\lambda}c(\frac{x}{\lambda}) + 2x$  is decreasing in  $\lambda$ , since its derivative with respect to  $\lambda$  is:

$$\frac{\partial LHS(\lambda)}{\partial \lambda} = -\frac{1}{\lambda^2}c\left(\frac{x}{\lambda}\right) - \frac{x}{\lambda^3}c'\left(\frac{x}{\lambda}\right) < 0$$

Which is negative for any  $x \geq 0$  since  $c > 0$  and  $c' > 0$  given that  $C(\cdot)$  is increasing and convex. When  $b_L \rightarrow 0$ ,  $b_T^M$  solves  $c(b_T^M) + 2b_T^M = 1$  and  $b_T^D$  solves  $\frac{1}{\lambda}c(\frac{b_T^D}{\lambda}) + 2b_T^D = 1$ . Since  $LHS(\lambda) = \frac{1}{\lambda}c(\frac{x}{\lambda}) + 2x$  is decreasing in  $\lambda$ , we have  $\frac{1}{\lambda}c(\frac{x}{\lambda}) + 2x > c(x) + 2x$  for any  $x$  given that  $\lambda < 1$ . Therefore, as  $b_L \rightarrow 0$ , the value of  $x$  that solves  $\frac{1}{\lambda}c(\frac{x}{\lambda}) + 2x = 1$  must be strictly lower than the value of  $x$  which solves  $c(x) + 2x = 1$ . So  $\Delta(b_L) = b_T^M(b_L) - b_T^D > 0$  as  $b_L \rightarrow 0$ . When  $b_L \rightarrow \frac{1}{2}$ ,  $b_T^M$  solves  $c(b_T^M) + 2b_T^M = 0$ . Given  $c(0) = 0$ , this means  $b_T^M = 0$ . Instead, when  $b_L \rightarrow \frac{1}{2}$ ,  $b_T^D$  still solves  $\frac{1}{\lambda}c(\frac{b_T^D}{\lambda}) + 2b_T^D = 1$ , so  $b_T^D > 0$ . Thus,  $\Delta(b_L) = b_T^M(b_L) - b_T^D < 0$  as  $b_L \rightarrow \frac{1}{2}$ . Therefore, we have (1)  $\Delta(b_L)$  is continuously decreasing in  $b_L$ , (2)  $\Delta(b_L) = b_T^M(b_L) - b_T^D > 0$  as  $b_L \rightarrow 0$ , and (3)  $\Delta(b_L) = b_T^M(b_L) - b_T^D < 0$  as  $b_L \rightarrow \frac{1}{2}$ , so we can apply the intermediate value theorem and conclude that there exists  $\bar{b}_L$  such that  $b_T^M < b_T^D$  if and only if  $b_L > \bar{b}_L$ .  $\square$

From Lemma 6, we can directly conclude that if  $b_L > \bar{b}_L$ , then  $b_T^M < b_T^D$  and therefore  $\hat{T}^{Manual} > \hat{T}^{Digital}$ . Since in equilibrium,  $T = \hat{T}$  both before and after the reform, then  $T_{Manual} > T_{Digital}$ .  $\square$

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## Tables

Table 1: Did the digitization reform affect tax collection?

Dependent variables:	IHS Tax collection (1)
Digitization of land records	-1.827*** (0.634) [0.01]
Dep. var. mean (in 000 PKR)	16278.9
District fixed effects	Yes
Fiscal year fixed effects	Yes
Observations	212

Notes: The unit of observation is a district-fiscal year. 'Digitization of land records' is a dummy variable that takes value 1 for phase 1 and 2 districts in every year from FY2012 and FY2013 respectively, and remains zero otherwise. IHS tax collection is the inverse hyperbolic sine of the amount of taxes, in thousand PKR, collected by the government in a district-fiscal year. Standard errors clustered at district level in parentheses. Wild clustered bootstrapped (with 10,000 replications)  $p$ -values in square brackets. Significance levels are denoted as: \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Table 2: Did the digitization reform affect the agricultural tax base?

	Farm profit per acre (1)	Satellite vegetation cover index (2)	Whether agri land irrigated? (3)	Log agricultural land owned (4)
Digitization of land records	4.909 (3.221) [0.156]	0.00597 (0.00571) [0.262]	-0.00945 (0.0510) [0.789]	0.0645 (0.0445) [0.174]
Dep. var. mean	15.5	0.53	0.12	7.69
District fixed effects	Yes	Yes	Yes	Yes
Fiscal year fixed effects	Yes	Yes	Yes	Yes
Observations	5,986	288	161,796	161,836

Notes: In column (1), the unit of observation is a household-survey wave. In columns (3) and (4), the unit of observation shifts to citizen-survey wave. For column (2), the unit of observation is district-fiscal year. ‘Farm-level profit per acre’ is the difference in the value of output per acre and the total expenses per acre and is based on HIES data sourced from [Beg \(2022\)](#), focusing on cultivating households across the survey waves of 2005, 2007, 2011, and 2013. For this measure, ‘Digitization of land records’ is a dummy variable that takes value 1 for phase 1 and 2 districts in the 2013 wave, and remains zero otherwise. ‘Satellite vegetation cover index’ is the Normalized Difference Vegetation Index (NDVI) with values ranging from -1 to 1. This data is from NASA’s MODIS land products. For this measure, ‘Digitization of land records’ is a dummy variable that takes value 1 for phase 1 and 2 districts in every year from FY2012 and FY2013 respectively, and remains zero otherwise. ‘Whether agricultural land irrigated’ is a dummy variable that takes value 1 when the agricultural land of the household is irrigated and is based on PSLM survey data. ‘Agricultural land owned’ measures the acres of agricultural land that is owned by households also based on the PSLM survey. We use the 2006, 2008, 2010 and 2012 waves of the survey. For these two measures, ‘Digitization of land records’ is a dummy variable that takes value 1 for phase 1 districts in the 2012 wave and remains zero otherwise. Standard errors clustered at district level in parentheses. Wild clustered bootstrapped (with 10,000 replications) *p*-values in square brackets. The dependent variables in Columns (4) is in logs, but the mean at the bottom of the table is presented in levels of the outcome variable. Significance levels are denoted as: \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Table 3: Bureaucrats' assessments of the tax base (district-level)

	Log assessed cultivated area	Log admin tax demands
	(1)	(2)
Digitization of land records	-0.106*** (0.0379) [0.004]	-0.600** (0.232) [0.015]
Dep. var. mean	1069.2	28685.6
District fixed effects	Yes	Yes
Fiscal year fixed effects	Yes	Yes
Observations	214	203

Notes: The unit of observation is a district-fiscal year. 'Digitization of land records' is a dummy variable that takes value 1 for phase 1 and 2 districts in every year from FY2012 and FY2013 respectively, and remains zero otherwise. The reported cultivated area is measured in thousand acres, while the administrative tax targets is in thousand PKR. We take the natural logarithms of both measures, but their means at the bottom of the table are presented in levels of the outcome variables. Standard errors clustered at district level in parentheses. Wild clustered bootstrapped (with 10,000 replications)  $p$ -values in square brackets. Significance levels are denoted as: \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Table 4: Did the digitization reform affect the performance of bureaucrats?

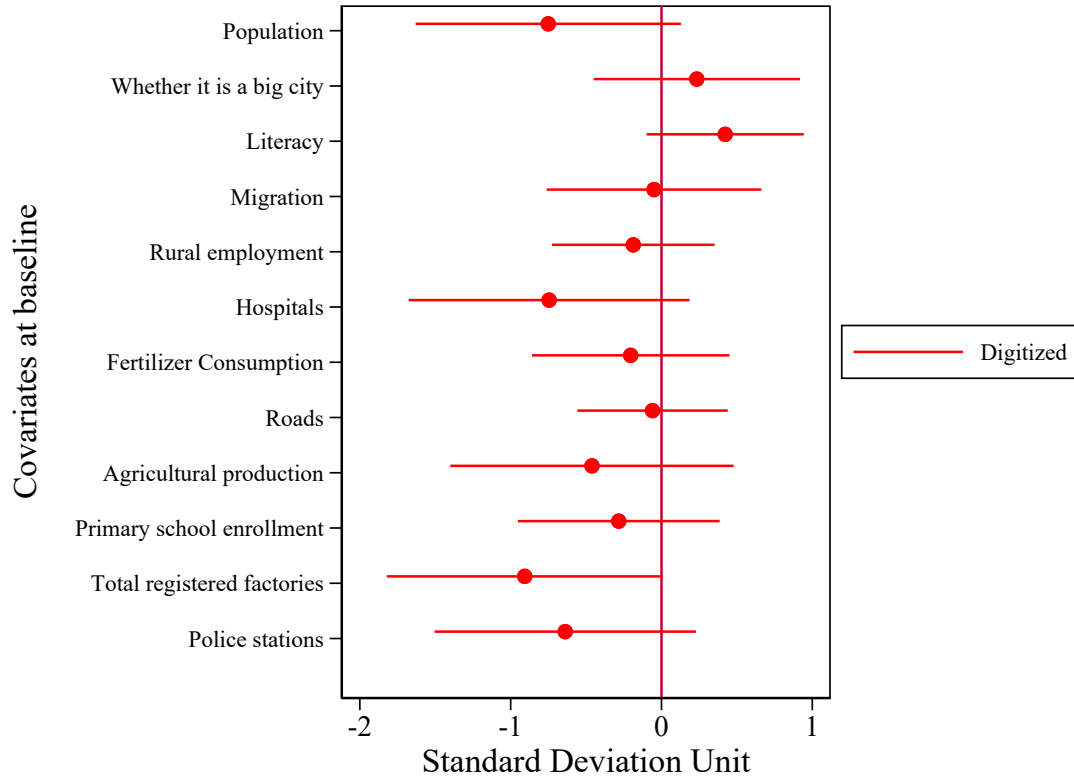
Dependent Variables:	Performance of bureaucrats			
	$\frac{\text{Tax collected}}{\text{Tax demand}} (\%)$	Whether at least 50% tax demand was collected	Whether at least 75% tax demand was collected	Share of months with zero collection
	(1)	(2)	(3)	(4)
Digitization of land records	-29.54** (14.09) [0.041]	-0.338** (0.158) [0.031]	-0.394** (0.152) [0.012]	0.225 (0.139) [0.111]
Dep. var. mean	53.9	0.53	0.43	0.19
Bureaucrat fixed effects	Yes	Yes	Yes	Yes
Fiscal year fixed effects	Yes	Yes	Yes	Yes
Observations	304	304	304	304

Notes: The unit of observation is a bureaucrat-fiscal year. ‘Digitization of land records’ is a dummy variable that takes value 1 for phase 1 and 2 districts in every year from FY2012 and FY2013 respectively, and remains zero otherwise. The first measure is the ratio of the tax they collected to the tax demand they issued. The second and third measure are dummy variables that take values 1 if at least 50% (75%) of the annual tax demand was achieved, and remains zero otherwise. The final measure is the share of months in the fiscal year in which no tax was collected. Standard errors clustered at district level in parentheses. Wild clustered bootstrapped (with 10,000 replications)  $p$ -values in square brackets. Significance levels are denoted as: \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .



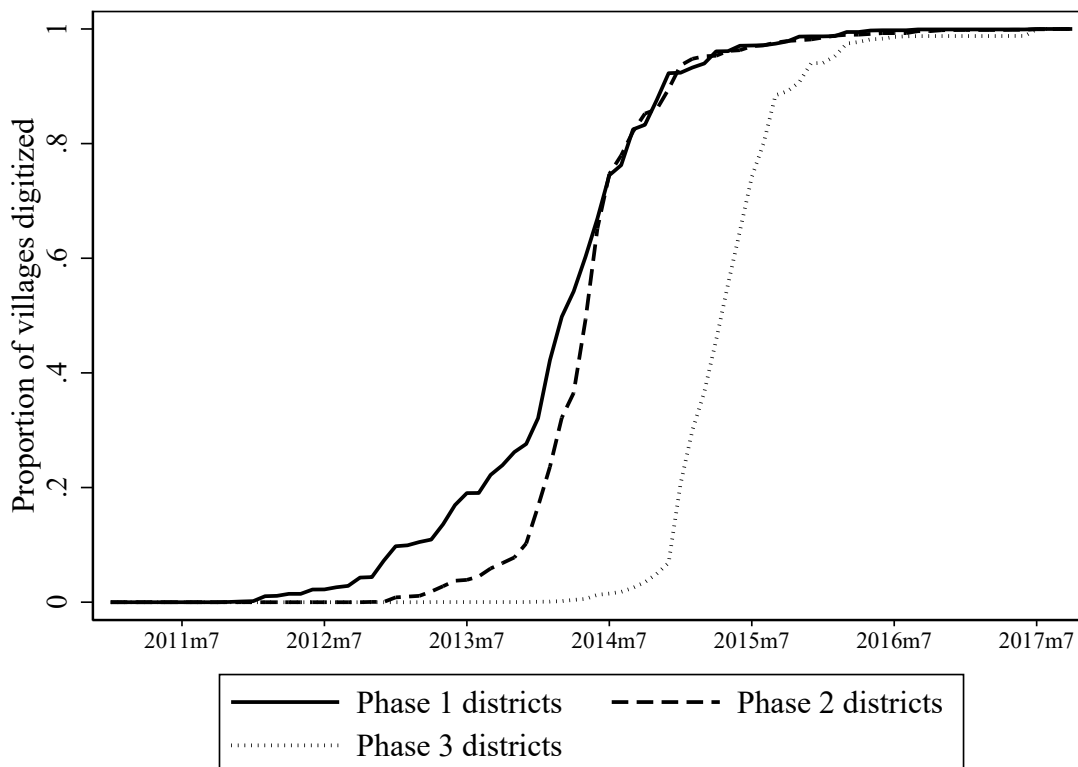
# Figures

Figure 1: Balance test of baseline characteristics between digitized and non-digitized districts



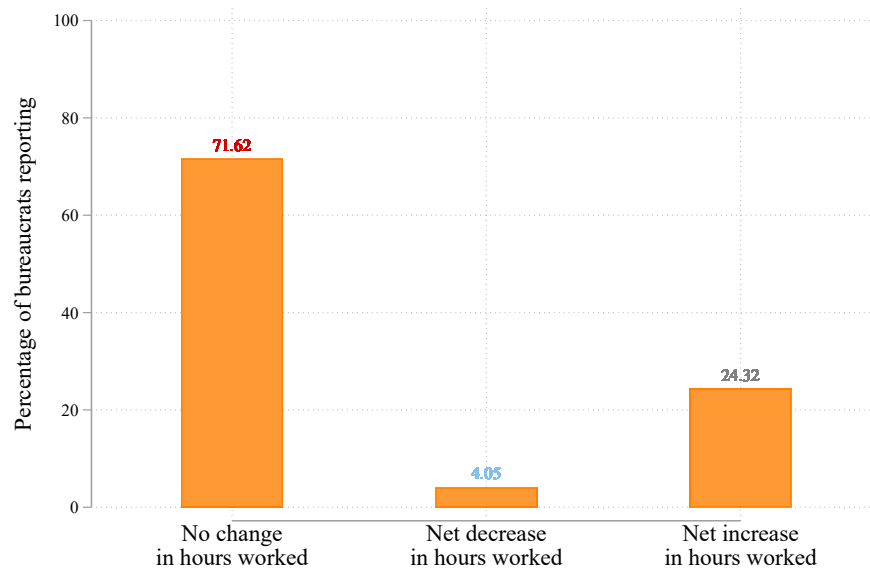
Notes: Data on baseline characteristics is from the Development Statistics of the Pakistan Bureau of Statistics 1997-2010. The point estimates are from a regression of the respective covariates on a dummy that takes value 1 if the district is in phase 1 or 2 of the digitization reform, and remains zero otherwise. The reference category are phase 3 districts. Intervals are 95% confidence intervals.

Figure 2: Phase wise rollout of the digitization reform over time



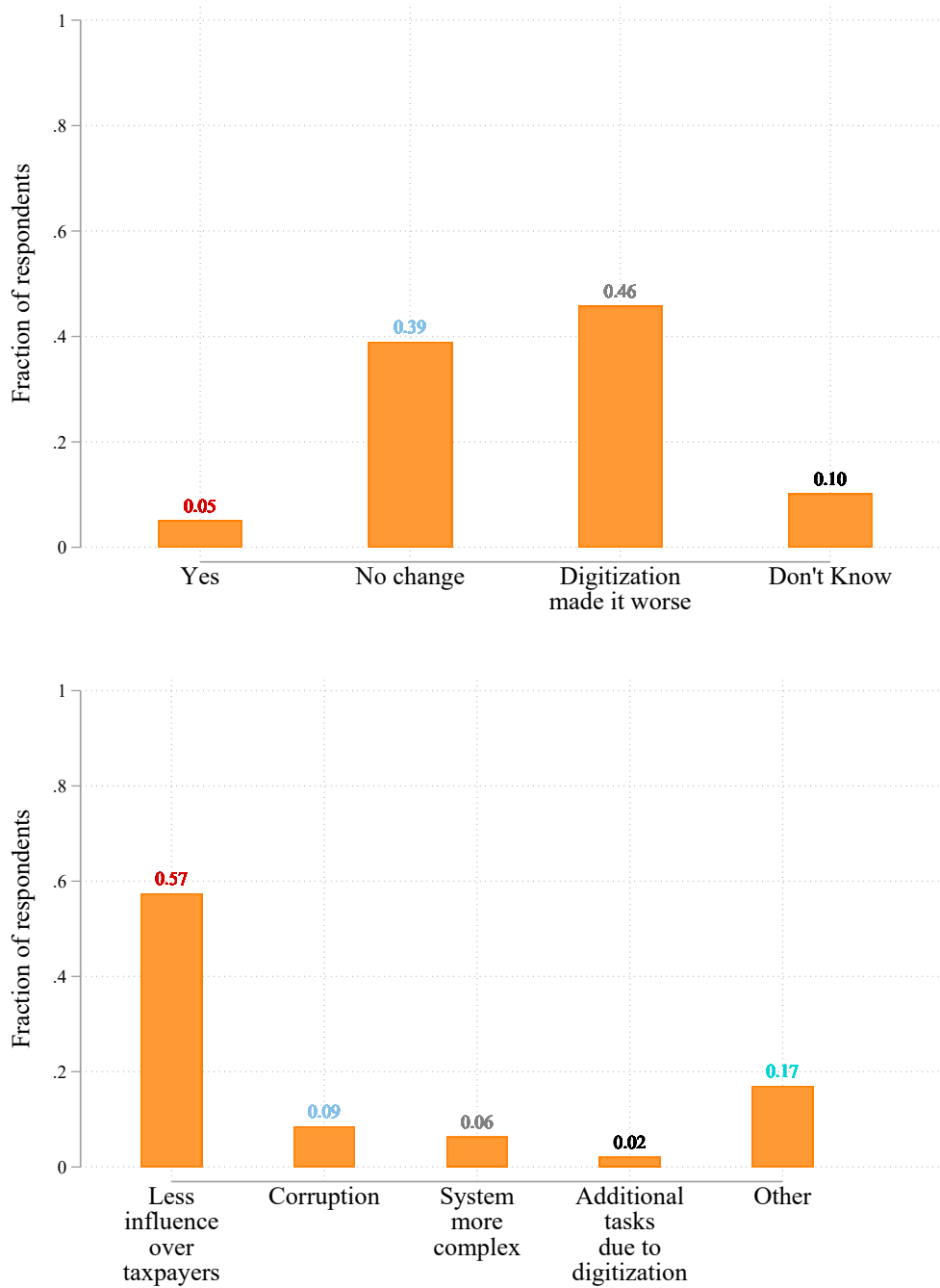
Notes: Districts that were planned to be digitized in phase 1 are Lahore, Lodhran, Hafizabad, Mandi Bahauddin, Nankana Sahib, Jhelum, Gujrat, Sialkot, Chakwal, Attock, Rawalpindi. Districts that were planned to be digitized in phase 2 are Bahawalpur, Gujranwala, Jhang, Layyah, Kasur, Multan, Muzaffargarh, Narowal, Okara, Rahim Yar Khan, Sargodha, Sheikhupura, Toba Tek Singh. Districts that were planned to be digitized in phase 3 were Bahawalnagar, Bhakkar, Chiniot, Dera Ghazi Khan, Faisalabad, Mianwali, Khanewal, Khushab, Pakpattan, Rajanpur, Sahiwal, Vehari.

Figure 3: Changes in hours worked by bureaucrats after the digitization reform



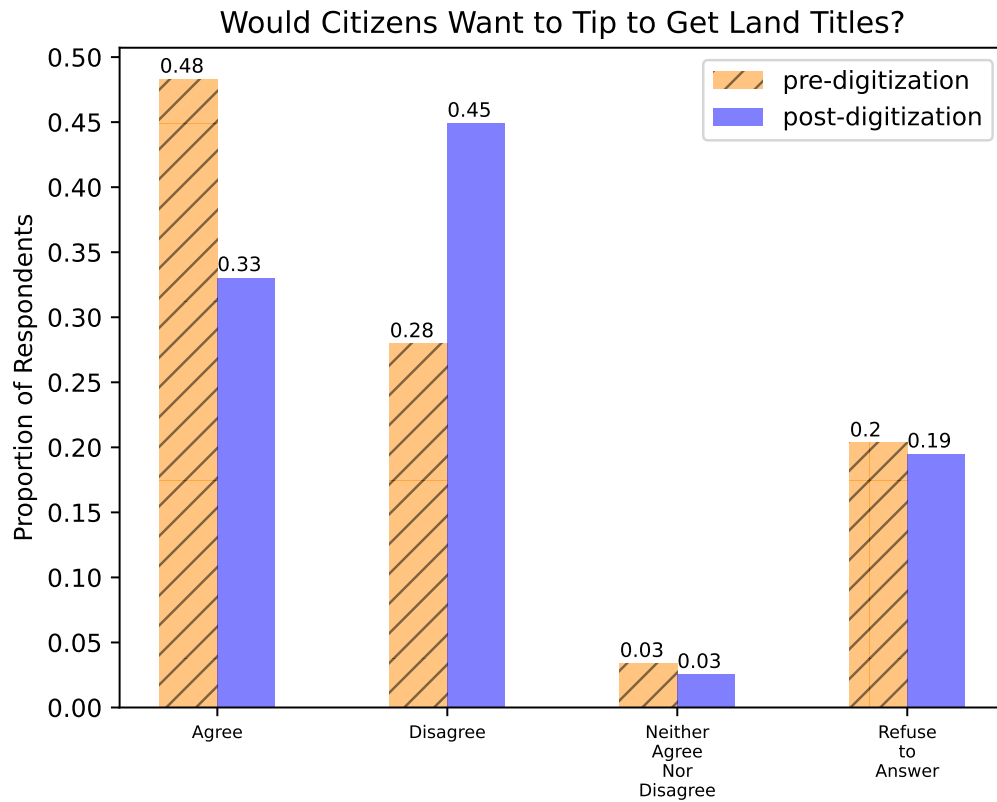
Notes: The figure is based on the bureaucrat survey restricted to the 118 bureaucrats who served as *Qanungo* between 2006-2013. The figure is based on responses to the questions “Do you think LRMIS (the digitization reform) has changed the official tasks that you are supposed to do? If so, what is the number of hours per day that were added / reduced because of these changes?” Based on these answers, we calculate the difference between hours added and hours removed. The first bar is the proportion that either responded ‘No’ to the first question or whose net difference was zero. The second (third) bar is the proportion of respondent for whom that difference was negative (positive).

Figure 4: Bureaucrats' views on the effect of digitization on tax collection



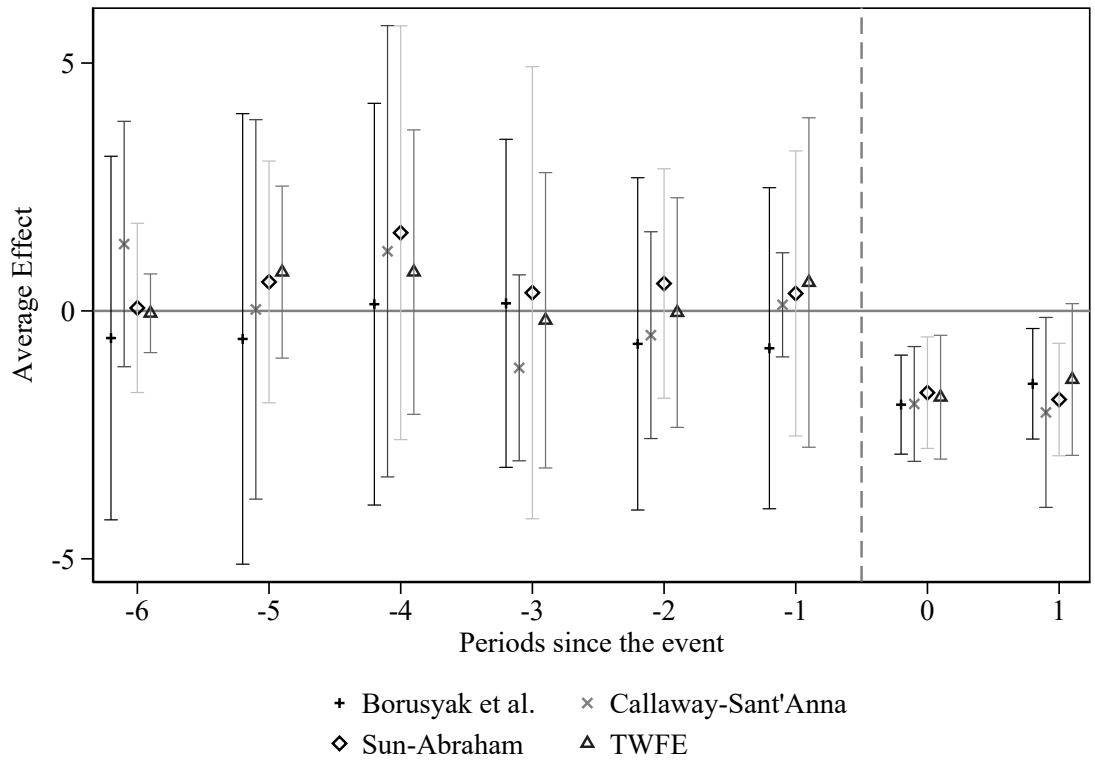
Notes: The figure is based on the bureaucrat survey restricted to the 118 bureaucrats who served as *Qanungo* between 2006-2013. The survey questions were "Do you think digitization has improved overall tax collection?" followed by "Please explain how?" The bottom figure is restricted to the 54 bureaucrats who responded 'digitization made tax collection worse' in the first question.

Figure 5: Do bureaucrats in charge of land titles receive bribes or “tips” for issuing them?



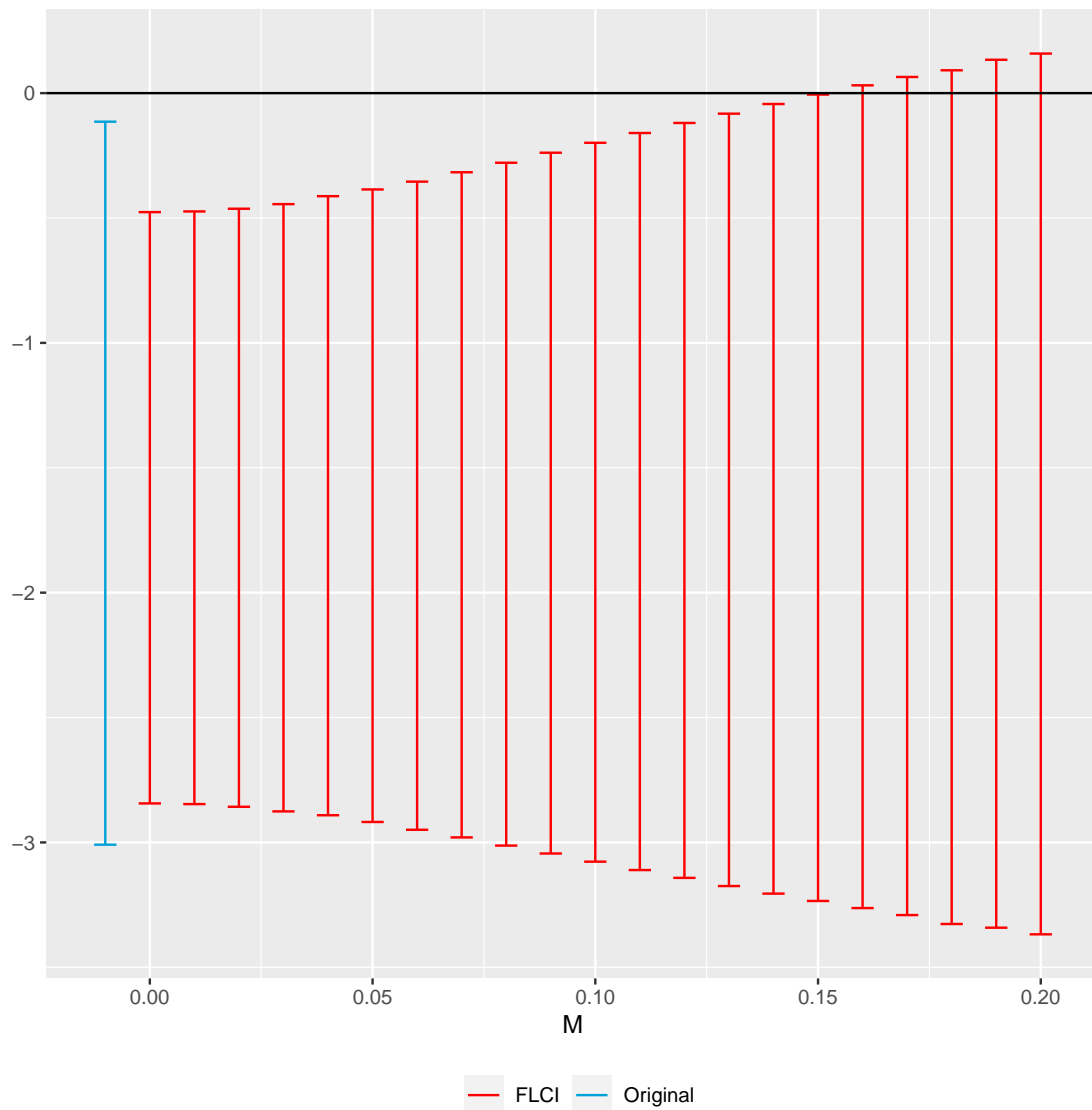
Notes: The figure is based on the bureaucrat survey. The figure shows the proportion of respondents that responded to, “People over there (in a revenue circle) would tip or want to tip a Patwari (bureaucrat’s subordinates) for issuing Fard (land title)” measured on a Likert scale. ‘Agree’, ‘completely agree’ were grouped into ‘agree’, while ‘disagree’, ‘completely disagree’ were grouped into ‘disagree’.

Figure 6: Event study plot for the district-level IHS tax collection



Notes: Data is at the district-fiscal year level. Each coefficient is obtained from a set of indicator variables that take values one if, in a given fiscal year, phase 1 or phase 2 districts were  $k$  years away from the introduction of digitized land records, as described in Equation 1. The reference year is FY2011 for phase 1 and FY2012 for phase 2. District and year fixed effects are included. Standard errors were clustered at the district level.

Figure 7: Robustness of the DID estimates to using the “more credible approach” (Rambachan and Roth, 2023)



Notes: The plot was created using the ‘second differences’ ( $\Delta^{SD}$ ) approach. FLCI refers to ‘fixed length confidence intervals’. The blue line is the confidence intervals for the coefficient obtained from the interaction term between digitization and post in an event-study regression similar to Equation 1. The reference year is FY2011 for phase 1 and FY2012 for phase 2.

# Supplemental Appendix

## A Appendix tables

Table A.1: Did the digitization reform affect district level tax collection? (robustness to different thresholds defining the beginning of a phase of digitization)

Dependent variables:	IHS Tax collection		
	First 1% villages digitized in a phase (1)	First 2% villages digitized in a phase (2)	First 5% villages digitized in a phase (3)
Timing of phases:			
Digitization of land records	-0.571 (0.572) [0.27]	-0.980* (0.508) [0.04]	-1.827*** (0.634) [0.01]
Dep. var. mean (in 000 PKR)	16679.9	16679.9	16278.9
District fixed effects	Yes	Yes	Yes
Fiscal year fixed effects	Yes	Yes	Yes
Observations	178	212	212

Notes: The unit of observation is a district-fiscal year. In Columns (1), and (2) 'Digitization of land records' is a dummy variable that takes value 1 for phase 1 and 2 districts starting in years FY2011 and FY2012 respectively, and remains zero otherwise. The difference between the two columns is the number of years in which the control group of districts (phase 3) remains untreated. In Column (1), phase 3 becomes digitized in 2013, while in column (2) phase 3 becomes digitized in 2014. Column (3) replicates Table 1 in which phase 1 becomes digitized in FY2012, phase 2 becomes digitized in FY2013 and phase 3 becomes digitized in 2014. IHS tax collection is the inverse hyperbolic sine of the amount of taxes in thousand PKR collected by the government in a district-fiscal year. Standard errors clustered at district level in parentheses. Wild clustered bootstrapped (with 10,000 replications)  $p$ -values in square brackets. Significance levels are denoted as: \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .



Table A.2: Correlation of planned and actual rollout of the digitization reform

Dependent Variables:	Number of villages digitized	
	(1)	(2)
Digitization of land records	173.3*** (24.00) [0.000]	
Phase 1		129.1*** (20.50) [0.000]
Phase 2		243.2*** (41.84) [0.000]
Dep. var. mean	34.14	34.14
District fixed effects	Yes	Yes
Fiscal year fixed effects	Yes	Yes
Observations	219	219

Notes: Data is at the district-fiscal year level. ‘Digitization of land records’ is a dummy variable that takes value 1 for phase 1 and 2 districts in every year from FY2012 and FY2013 respectively, and remains zero otherwise. Phase 1 is a dummy that takes the value one after FY2012 for all the districts that were planned to be digitized in phase 1, and remains zero otherwise. Phase 2 is a dummy that takes the value one after FY2013 for all the districts that were planned to be digitized in phase 2, and remains zero otherwise. Standard errors clustered at district level in parentheses. Wild clustered bootstrapped (with 10,000 replications)  $p$ -values in square brackets. Significance levels are denoted as: \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Table A.3: Correlation of tax collection and number of digitized villages

Dependent variable:	IHS Tax collection (1)
IHS num of digitized villages	-0.27** (0.12) [0.021]
Dep. var. mean (in 000 PKR)	16278.9
District fixed effects	Yes
Fiscal year fixed effects	Yes
Observations	212

Notes: Data is at the district-fiscal year level. ‘IHS number of digitized villages’ is the inverse hyperbolic sine of the number of villages that have digitized their land records. IHS tax collection is the inverse hyperbolic sine of the amount of taxes. Standard errors clustered at district level in parentheses. Wild clustered bootstrapped (with 10,000 replications)  $p$ -values in square brackets. Significance levels are denoted as: \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Table A.4: Did the digitization reform affect district level tax collection? (robustness to the use of inverse hyperbolic sine of tax collection)

	Median regression	Levels of tax	Intensive Margin	Extensive Margin
Dependent variables:	IHS tax collection (1)	Tax collection (000 PKR) (2)	Log tax collection (3)	Whether any tax collected? (4)
Digitization of land records	-0.780* (0.429) [0.0069]	-8053.4* (4120.2) [0.028]	-1.457*** (0.440) [0.0026]	-0.0349 (0.0376) [0.32]
Control mean of outcome	16278.9	16278.9	16278.9	0.93
District fixed effects	Yes	Yes	Yes	Yes
Fiscal year fixed effects	Yes	Yes	Yes	Yes
Observations	212	212	201	212

Notes: Data is at the district-fiscal year level. ‘IHS tax collection’ is the inverse hyperbolic sine of the amount of taxes. ‘Tax collection’ is the amount of taxes collected by the government in thousand PKR. ‘Log tax collection’ is the natural logarithm of tax collection. ‘Whether any tax collected’ is a dummy variable that takes value 1 if the tax collected in a district-year is positive, and remains zero otherwise. ‘Digitization of land records’ is a dummy variable that takes value 1 for phase 1 and 2 districts in every year from FY2012 and FY2013 respectively, and remains zero otherwise. While the dependent variables in Columns (1) and (3) are in IHS and log, respectively, their means are presented at the bottom of the table in levels (000 PKR). Standard errors clustered at district level in parentheses. Wild clustered bootstrapped (with 10,000 replications)  $p$ -values in square brackets. Significance levels are denoted as: \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Table A.5: Did the digitization reform affect district-level tax collection? (robustness to controlling for the ability of bureaucrats' managers)

Dependent Variables:	District level tax			Performance of bureaucrats		
	IHS Tax collection (000 PKR)	Tax collection (000 PKR)	$\frac{\text{Tax collected}}{\text{Tax demand}}$ (%)	Whether at least 50% tax demand was collected	Whether at least 75% tax demand was collected	Share of months with zero collection
	(1)	(2)	(3)	(4)	(5)	(6)
Digitization of land records	-1.831*** (0.623)	-7934.3* (4133.5)	-30.42** (12.81)	-0.347** (0.145)	-0.404*** (0.144)	0.238* (0.128)
Avg. ability of managers	0.826 (0.953)	1440.9 (9303.7)	33.87** (15.63)	0.324 (0.199)	0.331 (0.208)	-0.342* (0.179)
Dep. var. mean	16278.9	16278.9	53.9	0.53	0.43	0.19
District fixed effects	Yes	Yes	No	No	No	No
Bureaucrat fixed effects	No	No	Yes	Yes	Yes	Yes
Fiscal year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	210	210	301	301	301	301

Notes: In Columns (1) and (2), the unit of observation is a district-fiscal year, while in Columns (3) and (4) it is a bureaucrat-revenue circles-fiscal year. 'Digitization of land records' is a dummy variable that takes value 1 for phase 1 and 2 districts in years after FY2012 and FY2013 respectively, and remains zero otherwise. IHS tax collection is the inverse hyperbolic sine of the amount of taxes in thousand PKR collected by the government in a district-fiscal year. Tax collection is the amount of taxes in thousand PKR collected by the government in a district-fiscal year. The outcome variable in Column (3) is the ratio of tax collected to tax demand issued. The outcome variables in Columns (4) and (5) are dummy variables that take values 1 if at least 50% (75%) of the annual tax demand was collected, and remains zero otherwise. The outcome variable in column (6) is the share of months in the fiscal year in which no tax was collected by bureaucrats. While the dependent variable in Columns (1) is in IHS, the mean presented at the bottom of the table is in levels (000 PKR). Standard errors clustered at district level in parentheses. *Wild* clustered bootstrapped (with 10,000 replications) *p*-values in square brackets. Significance levels are denoted as: \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Table A.6: Did the digitization reform affect district-level tax collection? (placebo test based on different years of start of digitization)

Dependent variable:	IHS Tax collection	
	Phase 1 2006 Phase 2 2007	Phase 1 2009 Phase 2 2010
Placebo:	(1)	(2)
Digitization of land records	-0.475 (1.827) [0.78]	-0.394 (0.790) [0.59]
Dep. var. mean (in 000 PKR)	16800.8	16682.9
District fixed effects	Yes	Yes
Fiscal year fixed effects	Yes	Yes
Observations	212	212

Notes: The unit of observation is a district-fiscal year. The placebo is based on defining the 'digitization of land records' variable as a dummy that takes value 1 for phase 1 and 2 districts from years FY2006 (FY2009) and FY2007 (FY2010) respectively (instead of FY2012 and FY2013 in the main specification). IHS tax collection is the inverse hyperbolic sine of the amount of taxes in thousand PKR collected by the government in a district-fiscal year. Standard errors clustered at district level in parentheses. *Wild* clustered bootstrapped (with 10,000 replications) *p*-values in square brackets. Significance levels are denoted as: \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Table A.7: Comparison of districts whose land records were digitized in phase 1 and 2 with the districts in phase 3 (never-treated group)

Dependent variables:	IHS Tax collection	
	(1)	(2)
Digitization of land records (Phase 1 vs. Phase 3)	-2.008** (0.905) [0.032]	
Digitization of land records (Phase 2 vs. Phase 3)		-1.766*** (0.588) [0.0030]
Dep. var. mean (in 000 PKR)	16278.9	16278.9
District fixed effects	Yes	Yes
Fiscal year fixed effects	Yes	Yes
Observations	126	156

Notes: Data is at the district-fiscal year level. IHS tax collection is the inverse hyperbolic sine of the amount of taxes in thousand PKR collected by the government in a district-fiscal year. Phase 1 is a dummy that takes the value one for all the districts that were planned to be digitized in phase 1 in any years after FY2012, and remains zero otherwise. Phase 2 is a dummy that takes the value one for all the districts that were planned to be digitized in phase 2 in any years after FY2013, and remains zero otherwise. Phase 3 are those districts that are never treated in the sample period 2006-2013. Standard errors clustered at district level in parentheses. *Wild* clustered bootstrapped (with 10,000 replications) *p*-values in square brackets. Significance levels are denoted as: \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Table A.8: Did the digitization reform affect district-level tax collection? (Randomization inference  $p$ -value)

Dependent variable:	IHS Tax collection (1)
Digitization <sub><i>d</i></sub> × post <sub><i>t</i></sub>	-1.628*** (0.591) [0.004]
Randomization inference $p$ -val	0.021
Control mean of outcome	16278.9
District fixed effects	Yes
Fiscal year fixed effects	Yes
Observations	212

Notes: The unit of observation is a district-fiscal year. ‘Digitization of land records’ is a dummy variable that takes value 1 for phase 1 and 2 districts, and remains zero otherwise. Post is a dummy variable that takes the value 1 in years after FY2012, and remains zero otherwise. IHS tax collection is the inverse hyperbolic sine of the amount of taxes in thousand PKR collected by the government in a district-fiscal year. Randomization inference  $p$ -values (at the bottom of the table) are from permutation test similar to the randomization based inference test (Athey and Imbens, 2017; Young, 2019). We re-assign digitization over districts 10,000 times and compute the estimates under the null hypothesis that the treatment has no effect. Owing to this reassignment over just districts, we create separate dummy variables “Digitization” and “post”. Standard errors clustered at district level in parentheses. *Wild* clustered bootstrapped (with 10,000 replications)  $p$ -values in square brackets. Significance levels are denoted as: \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

Table A.9: Revenue-circle level regression of tax collection on digitized villages

Dependent variables:	IHS Tax collection (1)
Digitization of land records	-1.210*** (0.433) [0.01]
Dep. var. mean (in 000 PKR)	673.1
District fixed effects	Yes
Fiscal year fixed effects	Yes
Observations	3,974

Notes: Data is at the revenue circle-fiscal year level. 'Digitization of land records' is a dummy variable that takes value 1 for a revenue circle in every year after the first village in that revenue circle has been digitized and remains zero otherwise. IHS tax collection is the inverse hyperbolic sine of the amount of taxes, in thousand PKR, collected by the government in a district-fiscal year. Standard errors clustered at district level in parentheses. Wild clustered bootstrapped (with 10,000 replications)  $p$ -values in square brackets. Significance levels are denoted as: \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .





Figure B.2: An example of a digitized land record

رجسٹر حقداران زمین (مسل میعادتی)

مکان زمین		عرف / اپنی حد		قبضہ / تصرف			تاریخ		سال		کتاب نمبر		صفحہ نمبر	
1	2	3 (حصہ)	3 (3)	3 (3)	3 (3)	3 (3)	3 (3)	3 (3)	3 (3)	3 (3)	3 (3)	3 (3)	3 (3)	3 (3)
176	45 24	میرنگ سوہج دادا گنڈا آہر سرگت	راجہ برتھی دھیرہ	مٹوکر کونڈی مٹوکر صدر	مٹوکر روتی یکہ گہر	102	0-0-0	10480357	0-10-0	10	10	1	1	1
		گورنمنٹ ڈاٹ گورنمنٹ آف پنجاب	راجہ برتھی دھیرہ	مٹوکر کونڈی مٹوکر صدر	مٹوکر روتی یکہ گہر	102	0-0-0		0-10-0	10	10	1	1	1
		گورنمنٹ ڈاٹ گورنمنٹ آف پنجاب	راجہ برتھی دھیرہ	مٹوکر کونڈی مٹوکر صدر	مٹوکر روتی یکہ گہر	102	0-0-0		0-10-0	10	10	1	1	1

جمہوری سابق

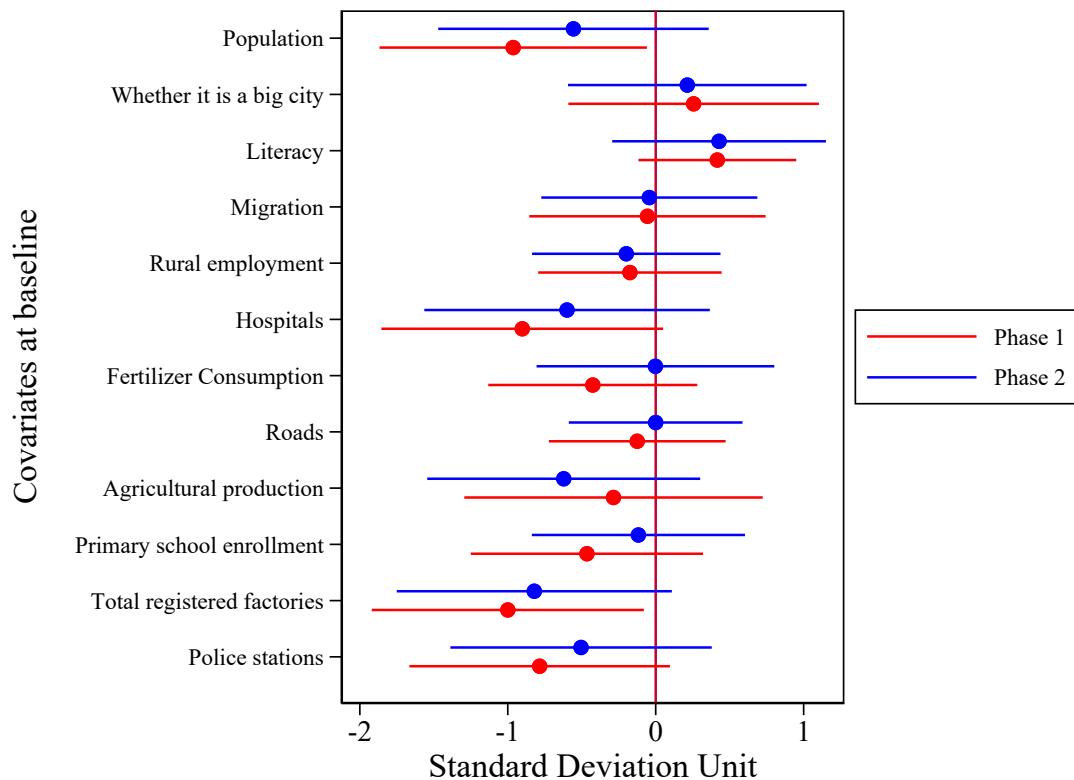
Notes: The source of the figure is: <http://cadastraltemplate.org/pakistan.php>

Figure B.3: A new bureaucracy set up to handle digitized land records



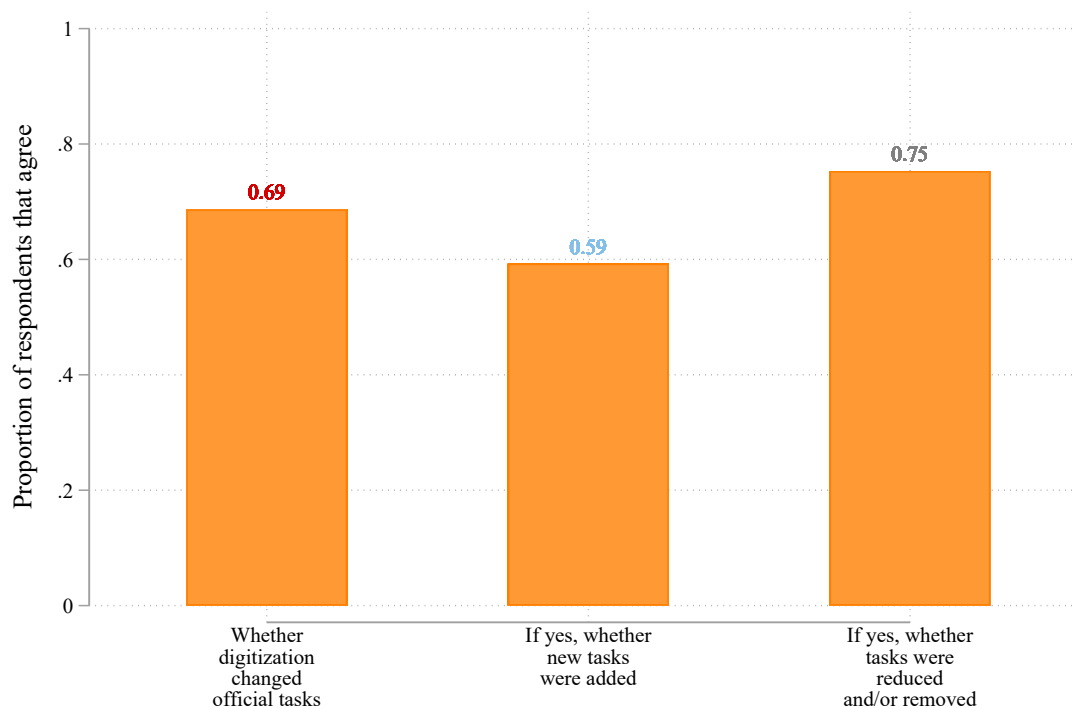
Notes: The source of the image is the World Bank (2017). New centers were set up across Punjab to deliver computerized land record services.

Figure B.4: Balance test of baseline characteristics of districts in phase 1 and 2 of the digitization reform



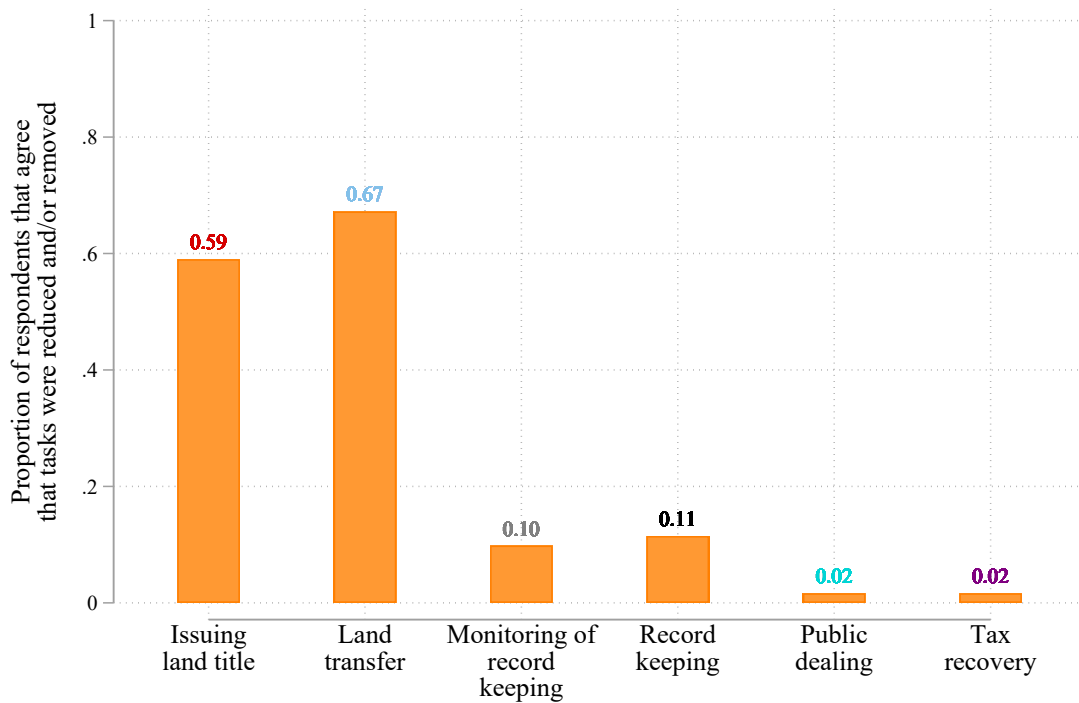
Note: Data on baseline characteristics are from the Development Statistics of the Pakistan Bureau of Statistics 1997-2010. The point estimates are from a regression of the respective covariates on a dummy that takes the value of one if the district lies in phase 1 or 2 of the digitization reform, and remains zero otherwise. The reference category are phase 3 districts. Intervals are 95% confidence intervals.

Figure B.5: Changes in the tasks of the bureaucrats after the digitization reform



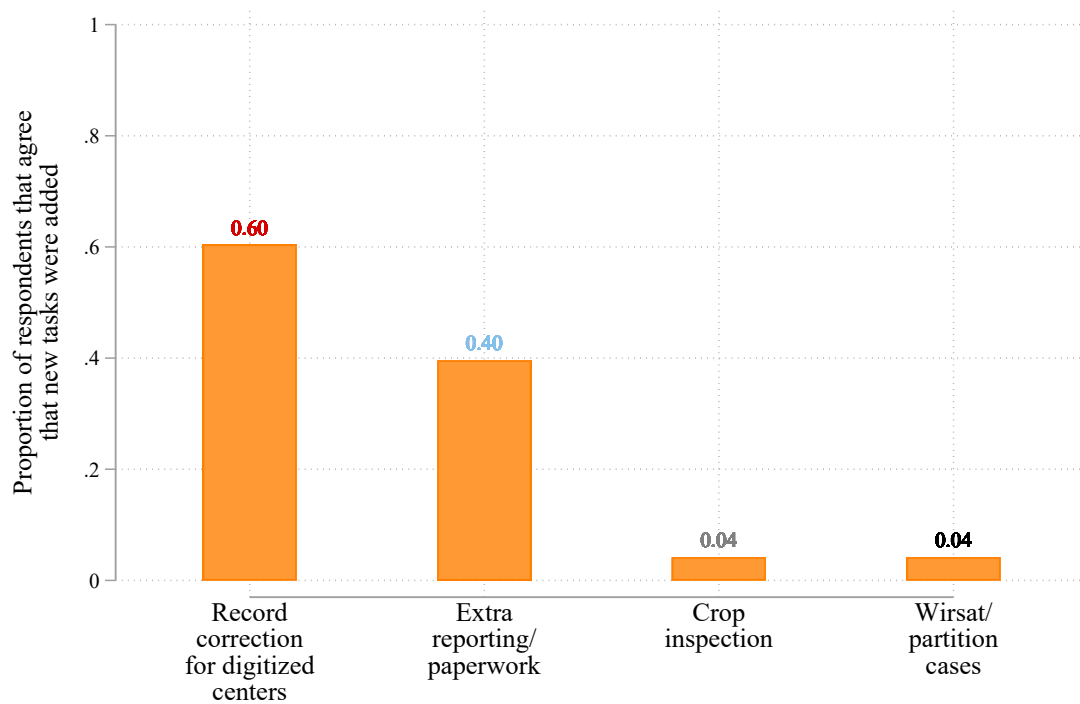
Notes: The figure is based on the bureaucrat survey restricted to the 118 bureaucrats who served as *Qanungo* between 2006-2013. The first bar plots the proportion of bureaucrats that agreed in the question “Do you think LRMIS (the digitization reform) changed the official tasks that you are supposed to do?”

Figure B.6: Bureaucrats' tasks reduced after the digitization reform



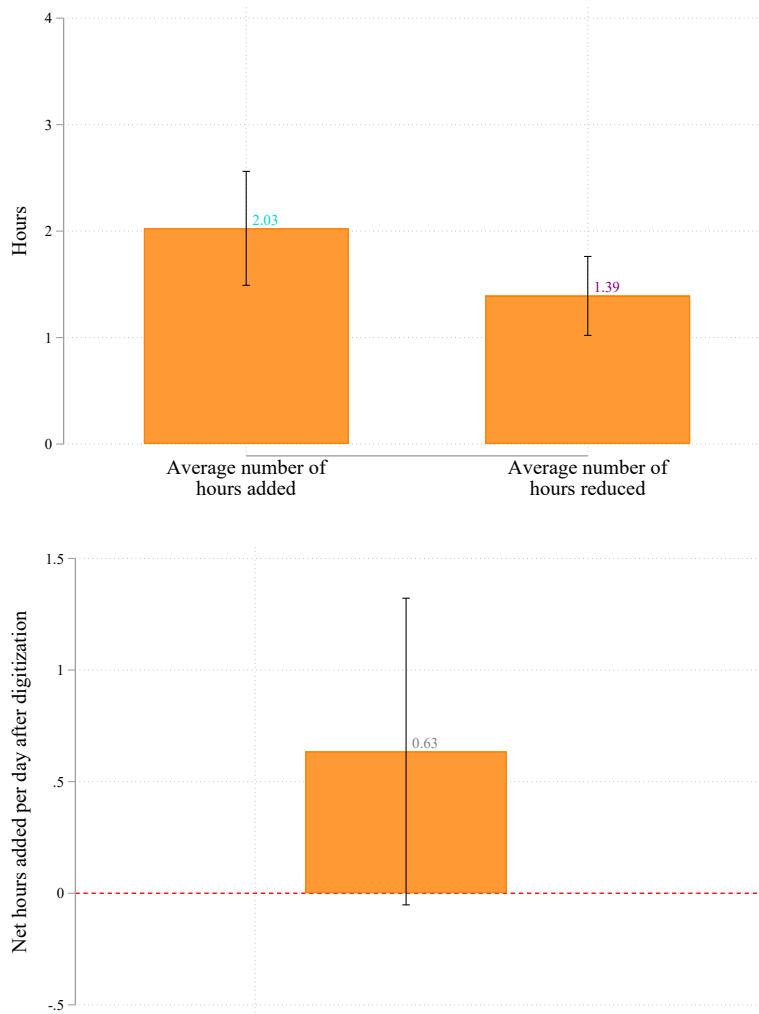
Notes: The figure is based on the bureaucrat survey restricted to the 81 bureaucrats who served as *Qanungo* between 2006-2013 and who agreed with the question “Do you think LRMIS (the digitization reform) changed the official tasks that you are supposed to do?”

Figure B.7: Bureaucrats' tasks added after the digitization reform



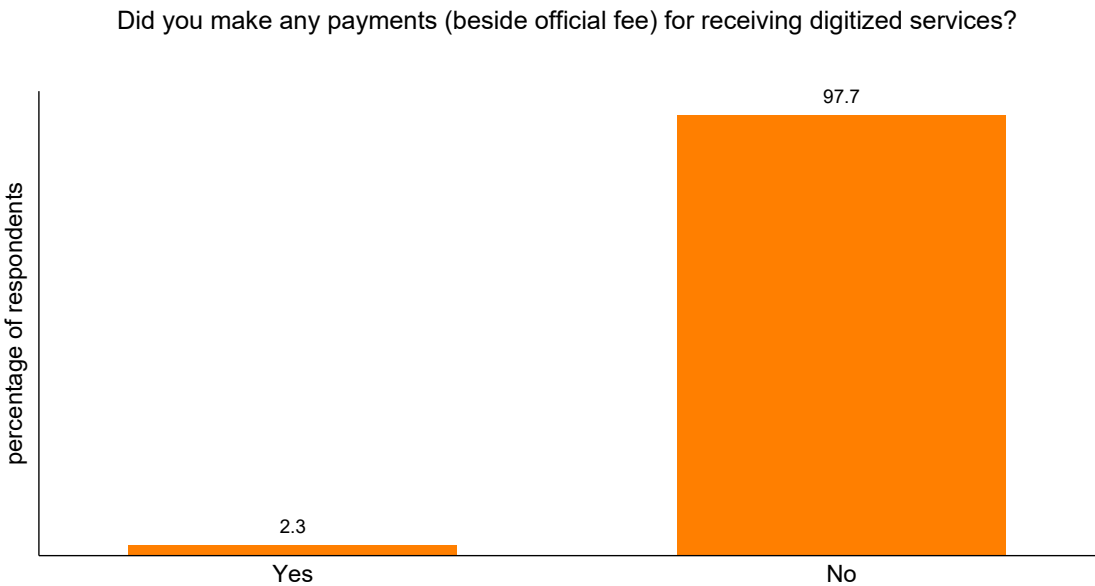
Notes: The figure is based on the bureaucrat survey restricted to the 81 bureaucrats who served as *Qanungo* between 2006-2013 and who agreed with the question “Do you think LRMIS (the digitization reform) changed the official tasks that you are supposed to do?”

Figure B.8: Changes in number of hours worked after the digitization reform



Notes: The figure is based on the bureaucrat survey restricted to the 118 bureaucrats who served as *Qanungo* between 2006-2013. The figure is based on responses to the question “Do you think LRMIS (the digitization reform) has changed the official tasks that you are supposed to do? If so, what is the number of hours per day that were added / reduced because of these changes?” Based on these answers, we calculate the average number of hours added and the average number of hours reduced across respondents. These are reported in the top panel. In the bottom panel we report the average net change in hours with 95% confidence intervals. The number is calculated by subtracting the number of hours reduced per day from the number of hours added per day, as reported by the bureaucrats.

Figure B.9: Bribe payments for getting land record services from the new bureaucracy



Notes: This data is from an endline citizen exit survey in 2016 on the services provided by the bureaucracy responsible for delivering digitized land record services.

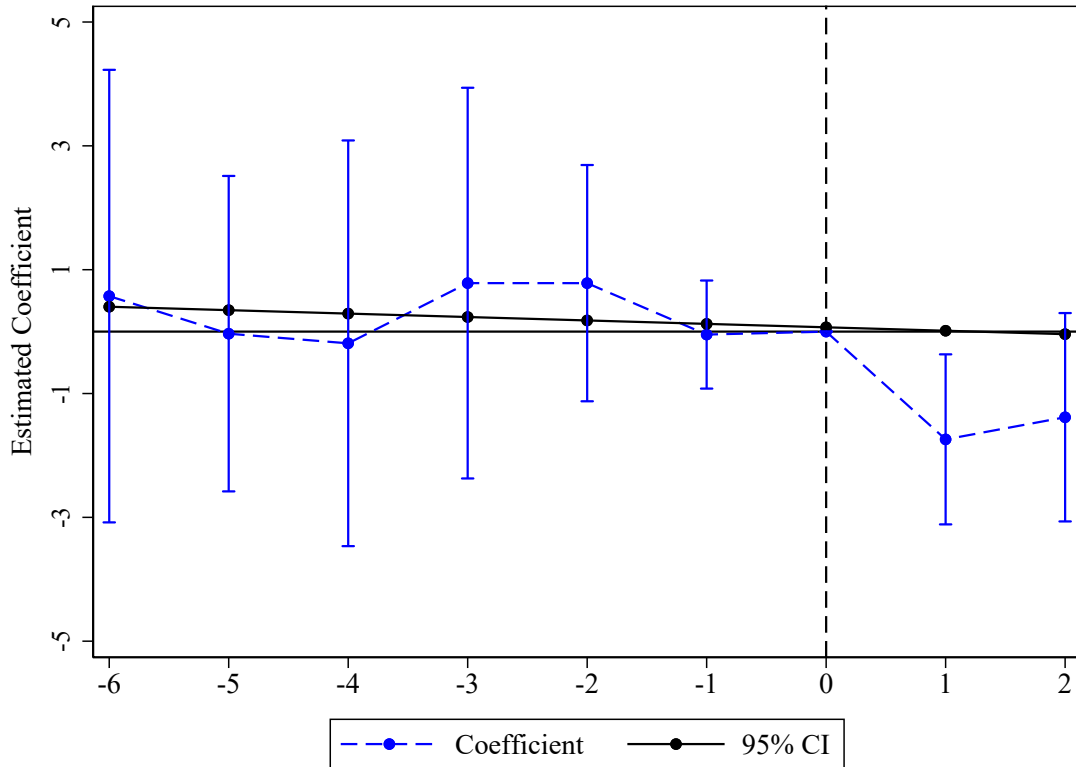


Figure B.10: Citizens' satisfaction with the new bureaucracy delivering digitized land record services



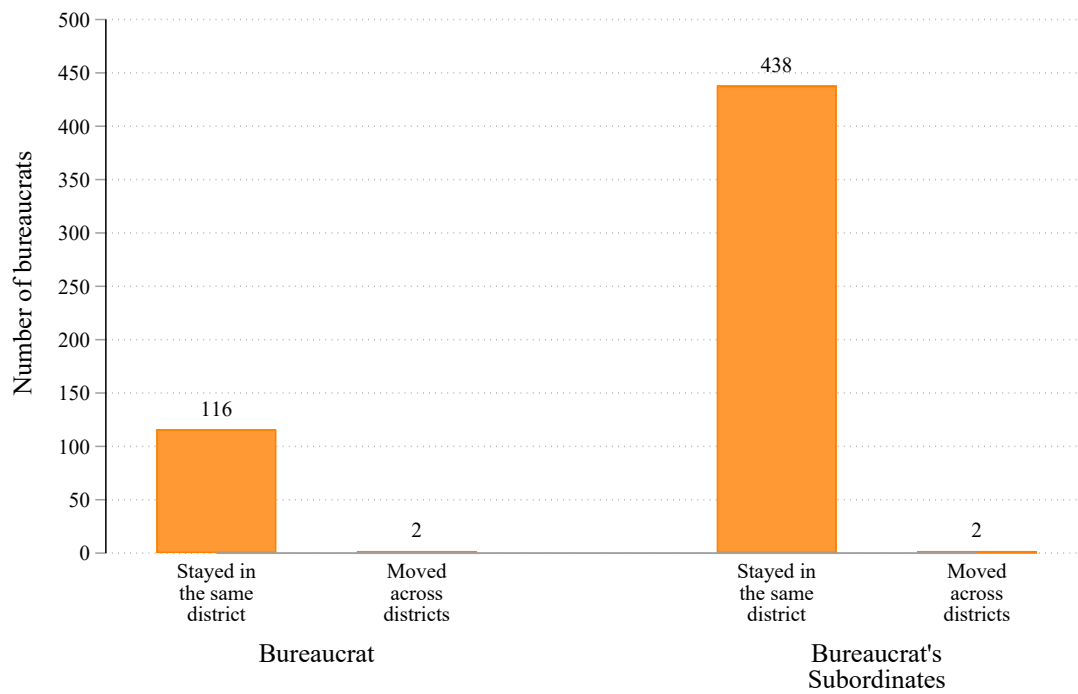
Notes: This data is from an endline citizen exit survey in 2016 on the services provided by the bureaucracy responsible for delivering digitized land record services. Big landlords are defined as those who own land acreage above the median.

Figure B.11: Event study plot for the district level IHS tax collection with a trend line based on pre-digitization data (TWFE estimator)



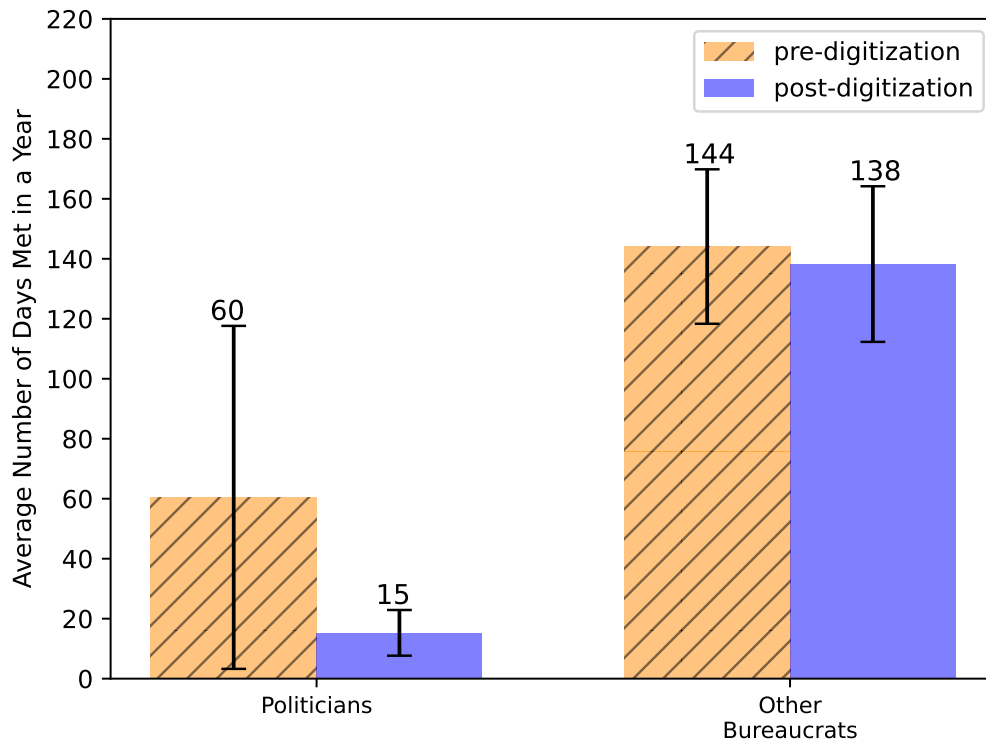
Notes: Data is at the district-fiscal year level. Each coefficient is obtained from a set of indicator variables that take values one if, in a given fiscal year, phase 1 or phase 2 districts were  $k$  years away from the introduction of digitized land records, as described in Equation 1. The reference year is FY2011 for phase 1 and FY2012 for phase 2. District and year fixed effects are included. Standard errors were clustered at the district level. The trend line is based on pre-digitization data (2006-2011). It is generated by regressing the pre-treatment coefficients (from Equation 1) on fiscal years 2006-2011.

Figure B.12: Movement of bureaucrats across districts



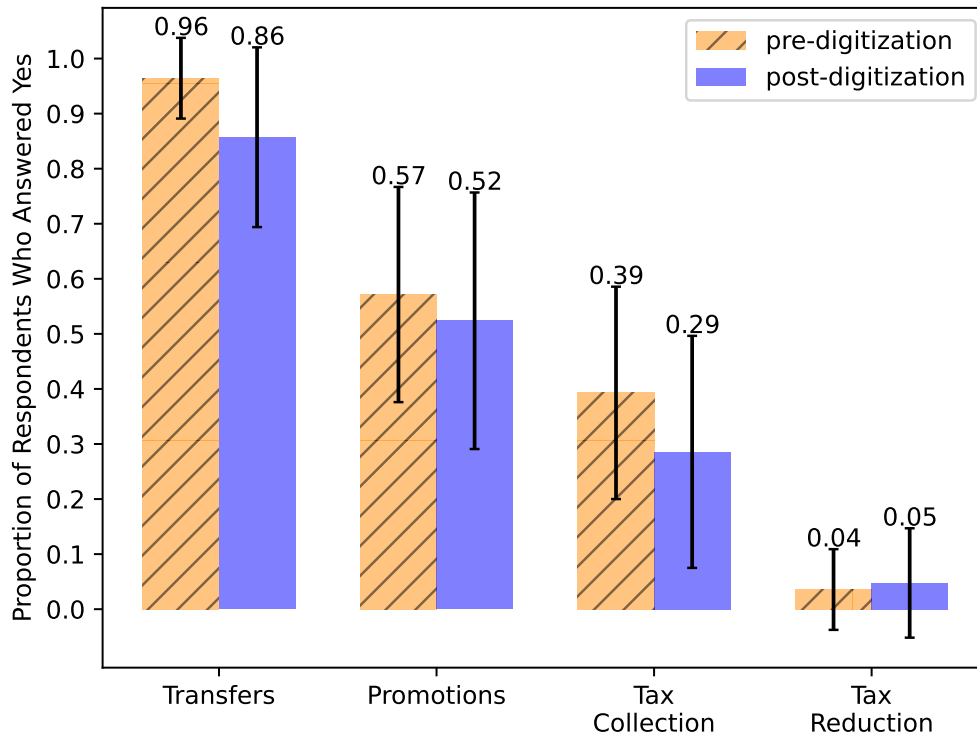
Notes: The figure is based on the bureaucrat survey. The left-hand side shows transfers among the bureaucrats that are the focus of this paper (Qanungos). The right-hand side shows transfers among their subordinates (Patwaris).

Figure B.13: Bureaucrats' social interactions with politicians and other bureaucrats before and after the digitization reform



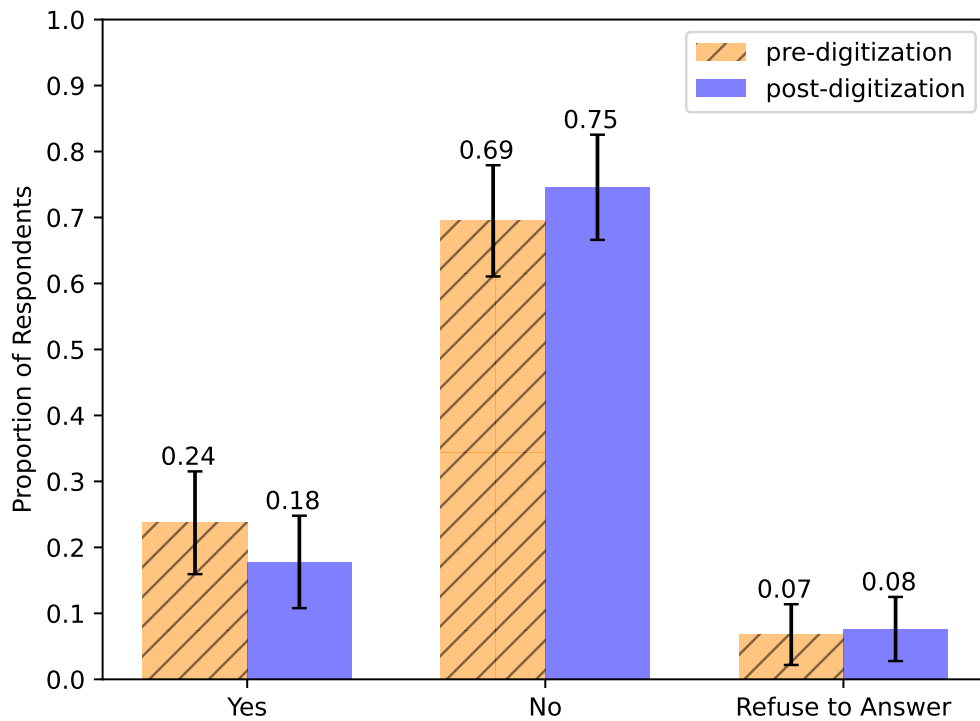
Notes: The figure is based on the bureaucrat survey restricted to the 118 bureaucrats who served as *Qanungo* between 2006-2013. We used a Likert scale to ask about the frequency of interactions between the respondent and politicians or other bureaucrats, before, and after, the reform. The Likert scale options were as follows: daily, twice a week, weekly, bi-monthly, monthly, quarterly, bi-annually, annually, less than once per year and never. We calculated the average number of days of interactions in a year for each bureaucrat based on these responses.

Figure B.14: Matters in which politicians interfere



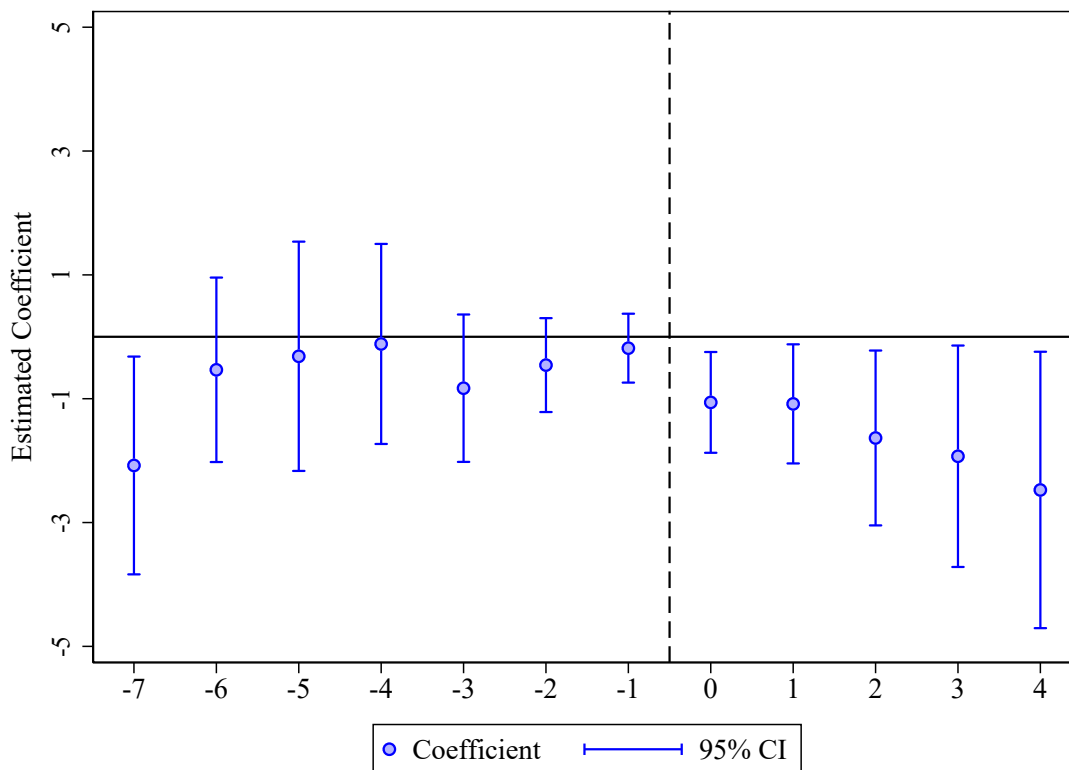
Notes: The figure is based on the bureaucrat survey restricted to the 118 bureaucrats who served as *Qanungo* between 2006-2013. Bureaucrats who responded 'yes' to the question: "In general, would you say that politicians interfere with the work of revenue officials in this revenue circle?" were further asked "On which matters politicians usually interfere with work?" The matters listed above were suggested by the research team along with the category of "others".

Figure B.15: Political interference in the work of bureaucrats



Notes: The figure is based on the bureaucrat survey restricted to the 118 bureaucrats who served as *Qanungo* between 2006-2013. The question was: "In general, would you say that politicians interfere with the work of revenue officials in this revenue circle?"

Figure B.16: Event study plot for the revenue circle level IHS tax collection using actual digitization of land records over time (effects for four years after digitization)



Note: Data is at the revenue circle-fiscal year level. Each coefficient is obtained from a set of indicator variables that take values one if, in a given fiscal year, a revenue circle were  $k$  years away from having at least one village in the revenue circle with digitized land records. Specifically, for revenue circle  $r$ , in district  $d$  and fiscal year  $t$  between 2006-2015, we estimate the following regression:

$$y_{rdt} = \mu_r + \mu_t + \sum_{k=-7}^{k=4} \beta_k Actual D_{k(rdt)} + e_{rdt}$$

where  $y_{dt}$  is the inverse hyperbolic sine (arcsinh) of the total tax collected in district  $d$ , during fiscal year  $t$ , that is,  $y_{dt} = \ln(\text{tax}_{dt} + \sqrt{1 + (\text{tax}_{dt})^2})$ ,  $\mu_r$  are revenue circle fixed effects,  $\mu_t$  are fiscal year fixed effects, and  $Actual D_{k(rdt)}$  is a set of indicator variables that takes value one if revenue circle  $r$  in fiscal year  $t$  was  $k$  years away from being digitized. We define a revenue circle as being digitized if at least one village in the revenue circle has been digitized. The error terms are clustered at the district level. The coefficients  $\beta_k$  estimate the effect of being treated  $k$  years before and after digitization. The omitted time period is the one right before the digitization year.

## C Data Sources

Figure C.1: The Board Of Revenues' (BOR) record room





Figure C.2: The BOR tax collection pro forma

AGRICULTURAL INCOME TAX DISTRICT MUZAFFARGARH,  
FOR THE MONTH OF September, 2007.  
PREVIOUS A-I-T.

S. No.	Name of Tehsil	Demand	Suspension	Net Demand Recoverable	Previous Recovery	Current Recovery	Total Recovery	Balance	Percentage Month	Total
1-	M. Garh	17102682	—	171,02,682	76650	9300	85950	1,70,16,732	—	1%
2-	Kot Addu	29353571	—	293,53,571	87793	38100	1,25,893	2,82,27,678	—	—
3-	Alipur	2079273	—	20,79,273	34,150	44,706	78856	2,00,64,417	2%	4%
4-	Talsi	18396542	—	1,83,96,542	50010	9,500	59,510	1,83,37,032	—	—
Total A		65932068	—	6,59,32,068	2,48,603	1,01,606	3,50,209	6,55,81,859	—	1%

CURRENT A-I-T.

1-	M. Garh	—	—	—	—	—	—	—	—	—
2-	Kot Addu	—	—	—	—	—	—	—	—	—
3-	Alipur	—	—	—	—	—	—	—	—	—
4-	Talsi	—	—	—	—	—	—	—	—	—
Total B		—	—	—	—	—	—	—	—	—
G.Total A+B		—	—	—	—	—	—	—	—	—

## D Sampling for the bureaucrat survey

The retrospective survey was carried out in 2020, with the main aim to rebuild career trajectories of bureaucrats between 2006-2013 (the years when the tax data is available). Our sampling frame therefore, included people who were in charge of revenue circles (*Qanungo*) as well as people who in the recent past had worked as a *Qanungo*. These included bureaucrats that had risen through the ranks via promotions and were in-charge of the tehsils: (*Tehsildars* and *Naib-tehsildars*).

We stratified on districts and randomly sampled tehsils within each district.<sup>44</sup> We next created a sampling frame by contacting the local offices. Using that sampling frame we selected the universe of *Tehsildars* and *Naib-Tehsildars* working in the selected tehsils in Punjab. One *Qanungo* working with each of the *Naib-tehsildars* was randomly selected for the survey. We found 118 respondents who worked as *Qanungos* between 2006-2013.<sup>45</sup>

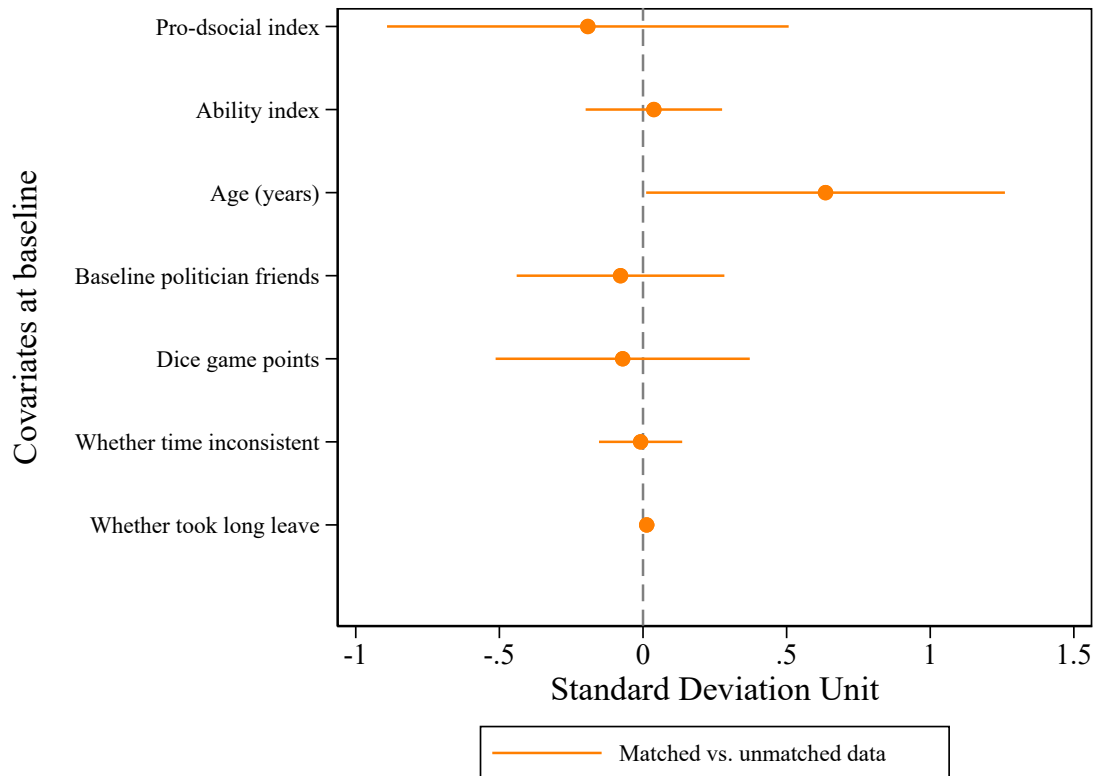
We could string-match the revenue circle names for 105 of those 118 respondents to match the survey data with the tax collection data. Of those the tax performance was missing for 27, so our final data set includes 78 respondents whose tax performance is observed between 2006-2013. In Figure D.1 below, we examine the potential systematic differences between these bureaucrats and the broader sample across various characteristics, utilizing data gathered from the bureaucrat survey. The only covariate showing marginal statistical significance is age. The  $p$ -value resulting from a joint significance test of all covariates in the figure is 0.5027, providing evidence that the sample is not systematically selected based on characteristic of the bureaucrats.

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<sup>44</sup>Out of 141 tehsils in Punjab, we were able to survey bureaucrats from 138 tehsils. We were unable to survey the bureaucrats from the following three tehsils: Nishtar Town (Lahore districts), Shahkot (Nankana Sahib district), Ahmed Pur (Sheikhupura district).

<sup>45</sup>To find these, we started by surveying a total of 610 bureaucrats across different levels of hierarchy. Of those, 488 responded to the second round of telephonic survey about their career trajectory. The telephonic survey was used to recap the career paths of the bureaucrats, while their perceptions of digitization as well as their traits were measured in-person. In the pilot, the field team suggested this approach as the most effective way to achieve the maximum response rate, as the combined length of the two exceeded 1 hour and 30 minutes.

Figure D.1: Balance test of characteristics of the bureaucrats in the sample (that were matched with the tax data) and those who remained unmatched



Note: Data on bureaucrats' characteristics is from the bureaucrat survey. The point estimates are from a regression of the respective covariates on a dummy that takes the value of one if the bureaucrats in the survey data were matched with the tax data, and remains zero otherwise. Pro-sociality index is created from five measures: Inclusion of Others in Self scale (Aron et al., 2004; Ashraf et al., 2020), whether they have donated blood, money donated in public good game, whether they do volunteer work and whether they give charity. Ability index is created from four measures: an incentivized matrix game and a memory game as in Hanna and Wang (2017), response to questions on general knowledge and revenue rules and regulations, respectively. Politician friends are the number of friends of the bureaucrats that are either federal or provincial politicians. Dice game points is a proxy for dishonesty and it is the total in an incentivized dice game as in Hanna and Wang (2017). Intervals are 95% confidence intervals.

## E Details on string matching revenue circles

We carried out an extensive string matching exercise to merge the tax, digitization and bureaucrats' careers datasets. We took the following steps to merge the three sets of data:

- As a first step we manually checked each revenue circle, tehsil and district in the tax data against their counterparts recorded in the digitization data from the Punjab Land Records Authority (PLRA) and allocated a unique ID to each.<sup>46</sup> There were 1125 revenue circles in total, out of which 838 were given IDs using this process.
- The district, tehsil and revenue circle names in the bureaucrat survey data was manually cleaned. There were 690 unique revenue circles-tehsil-districts in this data, out of these we were able to give IDs to 458.
- Finally, we merged all the three data on revenue circle, tehsil and district names.

We next checked the veracity of these data using further records from the government on details of revenue circle, tehsil and district names across Punjab. These were personally obtained from the government in 2020.

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<sup>46</sup>Digitization data from PLRA contained details of names of most of the tehsils and revenue circles except the following 19 (out of 141 in total) tehsils: Gujranwala Sadar, Kabirwala, Kharian, Shorkot, Khushab, Quaidabad, Jauharabad, Lahore city, Nishtar Town, Muzaffargarh, Depalpur, Renala khurd, Arifwala, Khanpur, Murree, Rawalpindi city, Rawalpindi Sadar, Rawalpindi Cantt and Daska.

## F Satellite vegetation cover data

We used NASA's MODIS land products to observe a satellite based vegetation cover index. MODIS vegetation indices provide consistent spatial and temporal comparisons of vegetation canopy greenness, a composite property of leaf area, chlorophyll and canopy structure. The normalized difference vegetation index (NDVI) are derived from atmospherically-corrected reflectance in the red, near-infrared, and blue wavebands. NDVI ranges from -1 to +1. If the NDVI values are negative it is highly likely that it's water. On the other hand, values close to +1 suggest that there is a high possibility that there are dense green leaves.<sup>47</sup>

NASA's MODIS land products rely on the Sinusoidal Tile Grid System, which divides earth into  $36 \times 18$  sinusoidal grids to locate a particular area on earth.<sup>48</sup>. Since we are only interested in the Punjab province of Pakistan, our first step was to locate the tiles where Punjab is located. Given the shapefile of districts of Punjab, we uniformly sample 10,000 points within each district and calculated their locations on the sinusoidal tile.<sup>49</sup> We find that all  $36 \times 10,000$  points lie within three tiles, namely (horizontal 24, vertical 5), (horizontal 24, vertical 6), and (horizontal 23, vertical 5). There are a total of  $4800 \times 4800$  pixels within each of the three tiles mentioned above, with each pixel having a  $250 \text{ m} \times 250 \text{ m}$  size. Moreover, data for each year is divided into time intervals of 16 days. This results in 23 different time intervals in a given year. For each 16-day time interval in a year, and for each of the 36 districts of Punjab, we obtained the NDVI values of all pixels belonging to that particular district and take the average to get the NDVI value for that particular district in that particular 16-day interval. Since each year has 23, 16-day intervals, we end up having a list of 23 different NDVI values for a particular district in a particular year. Following the method used in Beg (2022), we use the maximum value of that list as the NDVI value for that district for that year.

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<sup>47</sup>Details accessed at <https://gisgeography.com/ndvi-normalized-difference-vegetation-index/>

<sup>48</sup>Accessed at: [https://modis-land.gsfc.nasa.gov/MODLAND\\_grid.html](https://modis-land.gsfc.nasa.gov/MODLAND_grid.html)

<sup>49</sup>We decided to rely on this method rather than just consider the district's center and calculate their locations on the sinusoidal tile. This allows us a more holistic view of the vegetation cover of the district.