Misallocation in Indian Agriculture†

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Abstract

We exploit substantial variation in land-market institutions across Indian states and detailed micro panel data to study distortions in land rental markets and their impact on agricultural productivity. We find evidence that states with more rental-market activity feature less misallocation and over time reallocate land more efficiently. We develop a model of land rentals across heterogeneous farms to estimate land-market distortions in each state and assess their quantitative effect on agricultural productivity. Rentals have substantial positive effects on agricultural productivity. If farmers operate with their owned land instead of the actual cultivated land, agricultural productivity would decline by 22 percent on average and by more than 30 percent in states with substantial rental-market activity; whereas an efficient reallocation of land would further increase agricultural productivity by 29 percent on average and by more than 50 percent in states with highly distorted rental markets. Land market-distortions contribute to about one quarter of the differences in agricultural productivity across states.

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Keywords: Productivity, agriculture, distortions, land, rentals, states, India.

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1 Introduction

Low productivity in agriculture is a key contributor to the large income differences between rich and poor countries (Gollin et al., 2002; Restuccia et al., 2008). The misallocation of resources across heterogeneous production units has been identified as an important factor leading to low aggregate productivity (Restuccia and Rogerson, 2008; Hsieh and Klenow, 2009). The evidence suggests that poor countries allocate resources less efficiently across productive units than rich countries do, leading to a dampening of aggregate productivity. But the question of what causes this inefficient allocation of resources in poor countries is less well understood. The literature on agricultural productivity has identified institutions that shape policies and regulations around resource allocation to be an important source of this inefficiency, especially those surrounding land markets (Adamopoulos and Restuccia, 2014; Restuccia and Santaeulalia-Llopis, 2017).[1] However comparing measured data and institutions across different countries has proven to be a difficult endeavour. In this paper, we fill this gap by exploiting a unique feature of land institutions within India—a substantial variation in institutions across states arising due to both historical and contemporaneous conditions. We study how frictions in land rental markets alter farm's optimal participation and intensity in rentals, affecting the allocation of operated land across farms.

Household-level panel data from India allows us to focus on how market-wide restrictions on rental-market participation and farm-specific distortions can lead to resource misallocation. In this setting, barriers to trading land generate misallocation because the underlying land endowment is generally not allocated efficiently. A wedge between the marginal cost of renting in land and the marginal return to renting out may discourage farmers from participating in the rental market. Farm-level distortions also lead to inefficient rental market intensity, especially among productive farmers. We study these issues through a quantitative equilibrium model of heterogeneous farms and distorted land rental markets.

[1] See also Adamopoulos and Restuccia (2020); Chen (2017); Le (2020).

India provides a unique setting to study land markets and agricultural productivity for three reasons. First, despite recent strong aggregate productivity growth, labor productivity in agriculture and its growth remain very low. For instance, real gross domestic product per worker in agriculture in India is only 1.5 percent of that in the United States, whereas in non-agriculture this ratio is about 25 percent (data for 1985 from Restuccia et al., 2008). Similarly, the share of employment in agriculture in India remains very high—56 percent in 2005 and still 50 percent in 2014—indicative of low productivity levels and growth in the sector.[2] Second, there is substantial variation in land institutions and outcomes across states in India and we exploit these state-level differences in our analysis. For example, the variation in GDP per worker in agriculture across states in 2011-12 is a factor of 13.5-fold and the share of employment varies between 5 percent and 75 percent. These are enormous variations across states that resemble the patterns across countries but occur within a common national institutional framework. Institutionally, the market for buying/selling land is virtually non-existent in all states in India; most agricultural land is inherited (Foster and Rosenzweig, 2017). At the same time, states in India exhibit different propensities for rental market activity that allow us to study the effect of barriers to rental market participation. Third, critically, our detailed household-level micro data, collected under the same survey design across all states, distinguishes between cultivated land, owned land, and leased land. This feature allows us to study how state-level distortions affect decisions of individual farmers in the market for land.

We emphasize that there are large differences in land institutions across states in India (Besley and Burgess, 2000; Banerjee and Iyer, 2005; NITI Aayog, Govt. of India, 2016). Historically, different regions in India experienced dissimilar land tenure systems. After independence, the Indian Constitution (1949) granted states the right to enact and implement land reforms, as well as full authority over land-tenure issues. In the following decades, most states passed legislation to strengthen the rights of tenants, to abolish intermediaries, to

[2] Employment statistics from UNData, https://data.un.org/

constrain land inequality by enacting ceilings on landholdings, and to consolidate disparate landholdings (Besley and Burgess, 2000). A strategy employed by states in order to protect tenants from exploitation by landowners was to impose restrictions, to varying degrees, on leasing land. In some states, leasing of land is legally prohibited as in Kerala, whereas in others, land leasing is legally allowed but under restrictive clauses as in West Bengal where only sharecropping is allowed. These land and tenancy reforms also impacted a landowner's willingness to rent out land either formally or informally for fear of degrading their property rights. As a result, land-leasing activity differs markedly across states. The comparison across states within India allows us to focus on the role of differences in land institutions under a common set of national institutions, something that is often difficult to achieve in cross-country analyses.

To assess the importance of land markets in Indian states for agricultural productivity, we use micro household-level data from two waves (2004-2005 and 2011-2012) of the Indian Human Development Survey (IHDS) and a standard agricultural production framework. The IHDS survey contains not only detailed information on farmer-specific real agricultural output and inputs, but also information on the amount of land that a household owns and leases to or from other land-market participants. We exploit the panel structure of the data to construct a robust measure of farm-level total factor productivity (TFP) as the household fixed effect of a panel regression that also controls for district and time fixed effects. Using the estimates of farm productivity, we provide evidence on the link between rental-market activity and misallocation across states in India. First, *within states*, rental markets facilitate a more efficient allocation of resources. On average, farmers that rent in land are more productive and own less land, whereas farmers that rent out land are less productive and own more land. Second, *across states*, differences in rental market activity are associated with differences in the extent of misallocation. Third, *across time*, land is reallocated more efficiently in states with more rental-market activity.

To examine how distortions to rental market activity affect the allocation of land and agricultural productivity across states, we embed our agricultural production framework into an equilibrium model of heterogeneous farmers and distorted land markets. We model two sources of land-market distortions that create resource misallocation. Farmers face state-wide barriers to engaging in rental-market transactions, which manifest themselves as a difference between a farmer's cost and return to leasing land. This feature is motivated by the observations that land institutions vary across states and that these institutions imply disparate restrictions on renters and rentees. In addition, farmers face individual or idiosyncratic distortions to rental prices, a more traditional component of misallocation, which is parametrized as a function of farm productivity and a random component (Restuccia, 2019). We apply the structural framework by estimating the parameters of state-specific and farm-specific distortions using the first-order conditions from the farm's profit maximization problem. We identify distortion parameters using three sources of variation in the data: the share of farmers renting, the covariance between the marginal product of land and productivity across farmers, and the overall variance in the marginal product of land across farmers. We show that this parsimonious parameterization of distortions captures remarkably well the distinct patterns of land allocations and rental market activity across farms and states.

Using the estimated model, we perform three sets of counterfactuals to assess the quantitative role of land markets on agricultural productivity across states. First, we show that even the somewhat limited extent of land market activity across states has substantial effects on agricultural productivity. If farms operate only their owned land instead of the actual cultivated land, agricultural productivity would decline by 22 percent on average and as much as 37, 32, and 31 percent in the states of Assam, Rajasthan, and Orissa. Actual rentals have substantial positive effects on agricultural productivity in almost all states, but particularly those with low productivity, thereby mitigating differences in agricultural productivity across states. Second, we show that an efficient reallocation of land can substantially increase productivity in all states, even relative to Punjab, the state with the least distorted land markets. On average, an efficient reallocation of land increases agricultural productivity by 29 percent and 13 percent relative to Punjab. The increase in agricultural productivity is as high as 53 percent in Tamil Nadu and 47 percent in Karnataka, 33 and 28 percent relative to Punjab. Third, we decompose the contribution between farm-specific and state-specific distortions and find that farm distortions contribute to about two thirds of the reallocation gains. Our result is that a key component of land misallocation is the systematic farm-specific component that prevents the reallocation of land from less productive to more productive farmers.

In addition to the broad literature emphasizing resource misallocation referenced earlier, our paper connects with an important literature studying the impact of economic institutions in India (Besley and Burgess, 2004; Aghion et al., 2008; Boehm and Oberfield, 2018) and those that focus on land institutions (Besley and Burgess, 2000; Banerjee et al., 2002; Banerjee and Iyer, 2005; Besley et al., 2016). Our work builds on the literature using household-level data to study agricultural productivity in India such as Rosenzweig and Wolpin (1993) and Foster and Rosenzweig (1995). A key difference is that we focus on the effect of property rights institutions on agricultural productivity through misallocation. By emphasizing rental markets, we relate to a large literature connecting institutions and land markets (Deininger and Feder, 2001; Holden et al., 2011; Chen et al., 2017; Chari et al., 2017; Beg, 2019). Our strategy of studying variation across states in India is inspired by the work of Lahiri and Yi (2009) who emphasized the relative economic performance of West Bengal and Maharashtra, two important states in India, using a general equilibrium sectoral model.

The paper proceeds as follows. In the next section, we describe the basic institutional context of India, with particular reference to the determinants of differences in land market institutions across states. Section 3 presents a detailed description of the micro panel data and the agricultural production framework used to construct our measure of farm productivity.

In section 4, we characterize rental market activity across states and present evidence of the connection between rental market activity and misallocation. Section 5 describes the model, the estimation of land-market distortions, and the main quantitative results. We conclude in Section 6.

2 Institutional Context

In September of 2015, the National Institute for Transforming India (NITI Aayog), a policy think tank of the Government of India, formed an Expert Committee to "prepare a Model Agricultural Land Leasing Act, based on critical review of the existing agricultural tenancy laws of states and keeping in view the need to legalize land leasing" (NITI Aayog, Govt. of India, 2016).[3] The foremost observation in the committee's report was that legal restrictions on tenancy vary widely across states in India, and that these restrictions imply inefficient agricultural outcomes. Present day variation in tenancy laws across states is a combined result of differences in historical land tenure systems and land reforms being under the purview of state-level governments after independence in 1947. There were three main types of land revenue systems in British India: (1) landlord based, which assigned property rights to the landlord who was also in charge of collecting rents, (2) individual based, where individual farmers had property rights and taxes were collected directly from them, and (3) village based, where property rights were diffused depending on who was in charge of collecting land revenue. After independence, the 1949 Indian Constitution granted individual states full control over their own laws on land administration and land reform, giving states exclusive authority to legislate land-tenure issues, as a uniform nation wide policy would not work for all regions.

[3]NITI Aayog (Hindi for *Policy Commission*) was formed on January 1, 2015 to replace the Planning Commission of India instituted in 1950 to design strategic and long term policies and programmes for the Government of India (NITI Aayog, 2015).

The key elements in state land reforms were abolition of intermediaries, regulation of the size of land holdings (land ceiling legislation), and tenancy reforms to improve tenure security.[4] While all these reforms have shaped the present structure of land markets in India, we focus on tenancy reforms as they most directly affect the scope of land leasing in India. In what follows, we outline two major features of the resulting land market institutions in India that either directly or indirectly contribute toward the inefficient allocation of operated land across farmers: (1) Tenancy laws and (2) land records and titles in India.

Tenancy laws. Tenancy reforms enacted by state governments were largely designed to protect tenants from landlord exploitation by legally banning or imposing heavy restrictions (usually at the expense of the landowner) on the leasing of agricultural land. However, the roll out of tenancy reforms implied substantial differences in tenancy conditions across states (Table A.2 in the Appendix provides a summary of all tenancy reforms implemented by states between 1950 and 1980).

Based on the laws passed, states can be broadly classified into five categories (NITI Aayog, Govt. of India, 2016). (1) States that legally prohibited leasing out agricultural land without any exception such as Kerala, Jammu & Kashmir and Manipur. (2) States that allow leasing out only by certain categories of land owners, usually those that cannot cultivate by themselves, such as Bihar, Karnataka, Madhya Pradesh, Chhattisgarh, Uttar Pradesh, Uttarakhand, Himachal Pradesh, Tripura, Telengana and Odisha.[5] (3) States that do not explicitly prohibit land leasing, but the tenant acquires the right to purchase the leased land from the owner after a specified period of tenancy such as Punjab, Haryana, Gujarat, Maharashtra and Assam. (4) States where leasing is allowed under restrictive clauses such as Andhra Pradesh, Tamil Nadu, Rajasthan and West Bengal. For example, West Bengal allows

[4] See Appendix A for more details and discussion on all types of land reforms enacted by each state.

[5] Depending on the state, a subset of the following groups were exempted from the ban: those suffering from physical or mental disability, widows, unmarried, separated or divorced women, members of armed forces, seamen, among others.

only sharecropping and Andhra Pradesh has a minimum 6 year lease period requirement, and in both Andhra Pradesh and Tamil Nadu, once tenancy occurs, it can be terminated only through a state officer. (5) Scheduled tribe regions, transfer of tribal land to non-tribals, and in some cases even to tribals, on lease basis can be permitted only by a competent authority.

The implementation of tenancy reforms effectively reduced formal rental market activity in India. The share of households that report leasing land declined from 26% in 1970 to 12% in 2001 (World Bank, 2007). However, informal and short-term and mostly insecure tenancies continue to exist everywhere. Informal tenancies are sub-optimal as they lack recognition and thus access to institutional sources of credit and other benefits, and fail to cultivate their land efficiently (Dept. of Land Resource, Govt. of India, 2009). A further implication of restrictive tenancy laws is that it discourages land owners from leasing out land even in regions where leasing is legal or where informal leasing is widespread but ignored by the government. Some land owners even prefer to keep their land fallow for fear of losing their land in leasing arrangements. In fact, at least since the Ninth Five Year Plan (1997-2002) the Government of India has recognized that tenancy reforms have been unsuccessful in curbing informal tenancy and have led to underutilization of agricultural land. The government recognizes the need to legalize tenancy in order to protect the rights of the tenant and improve agricultural efficiency (Planning Commission, Govt. of India, 1997, 2002, 2007, 2012). This suggests that renters and rentees potentially face different types and magnitudes of frictions to participate in the land market, a property of the institutional setting that we exploit in our quantitative analysis.

Land records and titles. The land administrative system in India is generally considered inefficient, riddled with overlapping institutional mandates, ill-defined processes, and a high cost of service provision. For example, in 2004 India ranked 123 out of 140 countries in the cost of registering land transfers measured as a share of property value (hight stamp duties, complex regulations, and money and time spent on duplicative and inefficient procedures

(World Bank, 2007). Furthermore, land records and titles are unclear in India, leading to ill-defined property rights. These inefficiencies are a result of most institutions and processes for administering land being adopted from the British colonialists at independence with very little modifications since then. Land taxation contributed to 60% of total British revenue in the 1980s, and the land administration system established then was the primary tax collection method. In fact, the key institution amongst the web of administrative units responsible for managing land records in India is still called the *Revenue* Department even though its functions now include more than just tax collection.

Historical land records were primarily maintained for tax collection purposes by the British. However, the nature of land administrative units and the quality of land records developed depended mainly on the type of land-revenue system in each region. In landlord-based regions, cadastral maps were less maintained by the British government as the landlord was given property rights and revenue to be delivered was generally fixed for long periods. However, in regions with individual-based systems, regular maintenance of land records for individual farmers was important, and detailed title documents were created. Village-based regions varied depending on who was in charge of collecting rents. These regional variations in land records and titles were inherited by independent India, leading to vast regional differences in the quality of land property rights.

Another key feature of land titles in India is that they are presumptive (World Bank, 2007; Mishra and Suhag, 2017). India follows a *deeds* registration system (as opposed tot a *title* registration system) to facilitate land transactions. This means that registration of a legally valid deed results in the transfer of title to a given property. However, registration of a deed does not imply that the transaction itself was legal. The lack of good cadastral maps and land-record documentation and the historical purpose of the land registration system implies that the registrar has no obligation, or the ability, to check the validity of a transaction. However, the right claimed in a registered deed is usually given priority over unregistered ones, and subsequently registered deeds. A further complication in the system is that the burden of verifying the validity of a seller's ownership claims has to be borne by the buyer, who also incurs the cost of an invalid transaction. Under a title registration system the government provides and guarantees the information on past ownership, and the buyer cannot be sued for damages in case of a fraudulent transfer. While reforms have been implemented to consolidate and computerize land records (Digital India Land Records Modernization Programme), the outcomes are limited since states vary in terms of the scope of historically inadequate land records and the extent of computerized records presently (Mishra and Suhag, 2017). For example, as of 2019, the percentage of digital Record of Rights issued varies from close to 100% in states like Andhra Pradesh, Tamil Nadu, and Tripura to close to 3% in Haryana.[6]

We argue that the heavy costs inherent in land registration and the perceived low benefits may lead to sub-optimal levels of land market activity, in particular it may lead to land owners opting out of the system altogether. Without well defined property rights, farmers incentives to invest in long-term agricultural activities, and their ability to obtain credit (on the basis of legally owning farm land) are diminished. The lack of coherent property rights and ambiguities in the system also contribute to land-related conflicts to varying degree across states, which combined with the inefficiencies in the Indian judiciary system leads to a backlog of of land-related cases. For example, the share of pending land related cases that are more than 10 years old range from 45% in Gujarat (GJ) and Uttar Pradesh (UP) to 0% in Punjab (PB) and Haryana (HR). Long term land owners who have not been given any rights to land are not only blocked from accessing institutional benefits, but also from renting out the land due to fear of losing whatever rights they currently have or having their land get tied in a long legal battle. Similar to the effect of tenancy laws on rental activity, the land records system in India thus also leads to inefficient rental market activity. Note

[6]Source: Department of Land Resources, Ministry of Rural Development, Govt. of India. http://dilrmp.gov.in/faces/percent/rptComputerizationOfLandRecord.xhtml, accessed on June 30, 2020.

Table 1: Average Farm Size and Land Distribution in Indian States

	Land Operational Scale of Farms					
	Ag. Census (2010-11)			IHDS-II (2011-12)		
	Average Farm Size	% of Farms $\leq$ 2 Ha	% of Farms $\geq$ 20	Average Farm Size	% of Farms $\leq$ 2 Ha	% of Farms $\geq$ 20
India	1.18	45	4.0	2.12	71	1.0
State:						
Andhra Pradesh (AP)	1.13	55	1.0	2.41	60	0.7
Assam (AS)	1.00	49	8.6	1.15	88	0.0
Bihar (BR)	0.40	76	0.2	1.63	81	0.5
Gujarat (GJ)	2.03	30	4.8	3.64	50	1.4
Haryana (HR)	2.19	23	8.6	3.50	47	1.4
Karnataka (KA)	1.61	40	0.9	2.40	64	1.0
Kerala (KL)	0.22	77	1.8	1.61	75	0.0
Madhya Pradesh (MP)	1.82	34	2.5	3.68	50	1.7
Maharashtra (MH)	1.47	45	1.7	2.88	55	0.9
Orissa (OR)	1.03	70	1.3	1.16	85	0.0
Punjab (PB)	3.77	9	7.1	5.67	36	3.4
Rajasthan (RJ)	3.11	16	13.0	1.71	76	0.2
Tamil Nadu (TN)	0.81	61	2.5	2.84	82	1.9
Uttar Pradesh (UP)	0.77	65	0.5	1.57	77	0.2
West Bengal (WB)	0.75	81	4.0	1.03	89	0.0

Notes: All data refers to the land operational scale of farms. Data from 2010-2011 Agricultural Census and from micro IHDS-II 2011-2012 wave.

also that, inadequate property rights and informal tenancy may also lead to inefficient use of other resources.

Differences in land legislation and administration across states may be at the heart of contemporaneous differences in the operational scale of farms. Table 1 summarizes the distribution of cultivated land across farms in each state in India using data from the 2010-2011 Agricultural Census. Not surprisingly, there are substantial differences in the average farm size across states., for instance, Punjab's average farm size is almost 5-fold larger than that in Tamil Nadu and 19-fold larger than that in Kerala. In Punjab only 9 percent of farms operate less than 2 hectares of land, whereas the proportion is 61 percent in Tamil Nadu and 77 percent in Kerala. These enormous differences in the operational size distribution of farms resemble the large differences found across rich and poor countries and may be a symptom of productivity differences in agriculture (Adamopoulos and Restuccia, 2014).

3 Data

We provide details of the data and of specific variables in our analysis. We also describe our empirical measure of farm productivity and provide a characterization of efficient allocations as a benchmark for comparison and analysis.

3.1 Description

We use panel micro data from the India Human Development Survey (IHDS). This is a panel household survey that contains detailed information on agricultural and other commercial activities. The survey is representative at the state and nationwide level, and we use waves I, corresponding to the years 2004-2005, and wave II, corresponding to years 2011-2012. For households operating in the agricultural sector, the survey provides detailed information on farm output by crop and all inputs into production. We focus on the household farm as our main unit of analysis.

Real gross output. Farm households report the quantity units of crops produced, farm-specific prices, and total estimated revenue. Although more than 50 percent of farm-crop pairs are not sold in markets, farmers are asked to estimate the price they would receive for their crop if they would sell them. These prices are used to estimate farm-specific revenue. We construct a measure of real gross output at the farm level by aggregating the output of all crops produced by the household using constant farm-specific prices. We note that a more natural measure of real output would be to use common prices per crop. Currently, only IHDS wave-I contains information on crop-specific prices; the second wave reports only total estimated revenue per farm. Hence, we are limited by data availability. Nevertheless, we corroborate that our revenue measure of output correlates strongly with the real measure of output from wave-I using common prices across farms. Because we lack data on price deflators for agriculture by state, we use food CPI for agricultural workers in each state from the Indian Ministry of Labour and Employment. Constant prices over time and across states are expressed relative to wave-I and relative to Punjab.

Other inputs. For labor inputs, farms report family and hired labor, both in terms of days and hours worked in the last 12 months. Information on capital input in production is available in terms of quantities for machinery (e.g. bullcarts, pumps), draft animals, and capital services rented in and out. We aggregate these into a real household-level capital stock using 1997-1998 prices for machinery, the mean reported price for draft animals, and the reported mean annual interest rate on agricultural bank loans for converting capital services into a stock.[7] For intermediate inputs, farmers report expenditures on seeds, fertilizer, pesticides, and miscellaneous products. We lack data on the quantity of intermediate inputs and therefore deflate farm-level data on nominal intermediate input expenditures using village-level kerosene prices. While the level price of kerosene may differ from that of other intermediate inputs (e.g. fertilizer), our empirical approach requires only that we identify relative farm TFP within each state. We thus use kerosene prices to measure *relative* prices of intermediate input bundles across villages within a state. We believe kerosene prices are a good proxy since they mostly reflect the same relative trade costs that determine relative intermediate input prices. The survey also has detailed information on land used for agricultural purposes. Information on land inputs per household is available with respect to area cultivated, owned, rented in, and rented out. We use cultivated land as our measure of operated land by the farm household, but our analysis also exploits the information on

[7]Machinery prices are from Singh (2006), while other prices and interest rates are mean values of those reported in IHDS dataset.

the amount of cultivated land that is owned by the household, and the amount of cultivated land rented in and rented out.

Final sample. The IHDS-wave-I survey contains information on 41,554 households and we focus on the 13,971 farm households that cultivate a positive amount of land. From these, 11,066 households are also in IHDS-wave-II, 2,365 (17%) leave farming, 509 (4%) split up from the household, and 1,020 (7%) are lost to re-contact. From the panel sample, 2.5% have zero or missing values for output, labor, or intermediate inputs. We use a linear machine learning algorithm (Zou and Hastie, 2005) to impute the missing observations based on information from the household's state and district, cultivated land, real capital stock, as well as age, gender, and education of the household head. We emphasize, however, that our results are not affected by these imputations as output and factor input distributions are nearly identical when simply dropping the households with missing information from the sample. We also trim outliers, but rather than excluding households across the board at the top and bottom of a given distribution, we exclude households that experience large changes in land to output ratios between the two waves. In total, we drop 200 households (2%) that belong to the top 2% of households in terms of absolute changes in land-output ratios. After restricting our analysis to states with an estimated population of more than 20 million, we are left with a final sample of 8,642 households in 15 states for the analysis. The states in our final sample are: Andhra Pradesh (AP), Assam (AS), Bihar (BR), Gujarat (GJ), Haryana (HR), Karnataka (KA), Kerala (KL), Madhya Pradesh (MP), Maharashtra (MH), Orissa (OR), Punjab (PB), Rajasthan (RJ), Tamil Nadu (TN), Uttar Pradesh (UP), and West Bengal (WB). These states account for 97% of India's population and 92% of value added in agriculture in 2011. Our final sample also represents well the full sample in terms of the distribution of cultivated land. Moreover, the distribution of cultivated land in the final sample of the micro data captures fairly well the distribution of land from the agricultural census (see Table 1).

3.2 Farm Productivity and Efficient Allocations

We use the detailed micro data to estimate a permanent-component measure of farm productivity. We assume that households produce a homogeneous good and have a common production function that only differs in terms of their total factor productivity. The amount of gross output produced by a farm household i, in state s, in wave t, is given by:

$$y_{ist} = z_{ist}[(k_{ist}^{\alpha} l_{ist}^{\beta} n_{ist}^{1-\alpha-\beta})^{1-\theta} m_{ist}^{\theta}]^{\gamma}; \quad \alpha, \beta, \theta, \gamma \in (0, 1), \tag{1}$$

where y_{ist} is real farm gross output, k_{ist} is real capital stock, l_{ist} is operated land size, n_{ist} is total labor in hours, m_{ist} is real intermediate inputs. Note that the farm technology features decreasing returns to scale in variable inputs, which is a key element in determining the size of the farm given farm productivity, prices, and distortions. While specifying a common production function at the outset may seem restrictive, the evidence suggests that it generates reasonable distributions of farm productivity compared to an alternative approach of estimating the production function using panel data methods (Aragon et al., 2019). However, our panel data comprises only two waves and hence we are restricted to specifying the production function at the outset.

We set the parameter values for α, β, θ, and γ to expenditure shares of value gross output using a variety of data. We set $\alpha = 0.09$, $\beta = 0.36$, $\theta = 0.35$, and $\gamma = 0.54$, which imply a capital share of 4.9 percent, a land share of 19.4 percent, an intermediate inputs share of 18.9 percent, and a residual labor share of 56.8 percent which includes the farmer proprietor's income. These values are consistent with moments in developing countries (Adamopoulos et al., 2017; Chen et al., 2017). We emphasize that our estimates of farm-level productivity described below control for district and time fixed effects, hence, potential variation in these parameters across states are subsumed in fixed-effect controls. Similarly, in our analysis in Section 5, we focus on land as a composite input and, as a result, we abstract from variation in input ratios across states and farmers, variation that may be due to technology differences across farms.

We measure farm total factor productivity z_{ist} as a residual from the production function in equation (1) for each wave and state in the data and use it to estimate a more permanent measure of farm productivity that controls for time and space fixed effects. In particular, using the district location information of farmers, denoted by d, in each state we estimate:

$$\ln z_{ist} = \ln z_{st}^{d} + \ln z_{s}^{d} + \ln z_{is} + \nu_{ist}, \tag{2}$$

where $\ln z_{st}^{d}$ is a district-time fixed effect that captures time-varying price and weather effects at the local level, $\ln z_{s}^{d}$ is a district fixed effect that captures time-invariant productivity differences across districts such as land quality differences, and $\ln z_{is}$ is our measure of farm TFP that reflects persistent productivity differences across farmers within a state. In our final sample, there are on average 17 districts per state and an average district accounts for about 0.6% of all farmers in our sample.

Despite the limited time dimension of the data, the dispersion in farm productivity (measured as the standard deviation of log productivity) is 0.71 nationwide using our fixed-effect component of farm TFP, whereas the dispersion in productivity is 1.04 measured for measured farm TFP in the cross section of farms for the second wave. Hence, time and space variation reduces the cross-sectional dispersion in farm TFP by about 30 percent. Table 2 summarizes the distribution of farm TFP for India as a whole and for each state in our sample. We observe substantial dispersion in farm productivity in all states, with a standard deviation of log farm productivity of 0.51 in West Bengal and 0.8 in Kerala. We note that there are substantial differences in measured TFP across states in India. For instance, measured agricultural TFP in Punjab is 4.8-fold larger than in Orissa, 2.8-fold larger than in Maharashtra, and 3.1-fold larger than in West Bengal, see the first column in Table 2. But we emphasize that only a small component of these differences across states, about

Table 2: Total Factor Productivity (TFP) in Agriculture across Indian States

	Agriculture TFP relative to Punjab		Distribution of log Farm TFP		
	Actual	Permanent	SD	90 − 10	75 − 25
India	0.37	0.86	0.71	1.78	0.89
State:					
Andhra Pradesh (AP)	0.30	0.80	0.71	1.77	0.98
Assam (AS)	0.27	0.80	0.63	1.42	0.72
Bihar (BR)	0.31	0.92	0.61	1.49	0.73
Gujarat (GJ)	0.52	0.81	0.85	2.12	1.18
Haryana (HR)	0.51	0.91	0.65	1.60	0.81
Karnataka (KA)	0.33	0.82	0.84	2.16	1.09
Kerala (KL)	0.71	0.74	0.80	1.90	1.01
Madhya Pradesh (MP)	0.40	0.88	0.70	1.79	0.88
Maharashtra (MH)	0.36	0.83	0.71	1.78	0.91
Orissa (OR)	0.21	0.96	0.54	1.35	0.67
Punjab (PB)	1.00	1.00	0.67	1.79	0.85
Rajasthan (RJ)	0.28	0.86	0.80	2.03	0.98
Tamil Nadu (TN)	0.31	0.72	0.67	1.78	0.89
Uttar Pradesh (UP)	0.30	0.94	0.64	1.67	0.89
West Bengal (WB)	0.32	0.96	0.51	1.33	0.65

Notes: Agriculture TFP in each state is measured TFP computed as the ratio of aggregate agricultural gross output relative to aggregate composite inputs using the second wave of the micro data. Actual refers to measured TFP using actual gross output for each farm. Permanent uses the resulting gross output from actual inputs and the estimated permanent (farm fixed effect) measure of farm TFP. Statistics of the distribution of log farm TFP refer to the estimated permanent component of farm TFP.

12 percent, is accounted for by differences in measured aggregate TFP using our estimated farm TFP. A large component of state differences (most of it in many states) is accounted by the state fixed effects which our current analysis abstracts from. We discuss below how misallocation can potentially connect with these state-level differences.

A useful benchmark in comparing allocations and aggregate outcomes across states in India is the efficient allocation—that is the allocation that maximizes aggregate output in a state given resources—and the associated aggregate outcomes. We solve for the state-level efficient allocations by solving the farm-level allocations of capital, land, labor, and intermediates that maximizes aggregate output subject to state aggregate capital, land, labor and intermediates K_s, L_s, N_s, M_s. This problem can be solved at each date but we drop time subscripts for convenience:

$$\max_{\{k_{is},l_{is},n_{is},m_{is}\geq 0\}_{i=1}^{F_s}} \sum_{i=1}^{F_s} z_{is}[(k_{is}^{\alpha} l_{is}^{\beta} n_{is}^{1-\alpha-\beta})^{1-\theta} m_{is}^{\theta}]^{\gamma},$$

subject to

$$\sum_{i=1}^{F_s} k_{is} = K_s \qquad \sum_{i=1}^{F_s} l_{is} = L_s \qquad \sum_{i=1}^{F_s} n_{is} = N_s \qquad \sum_{i=1}^{F_s} m_{is} = M_s.$$

The efficient allocation involves allocating factors across the given set of F_s farmers in state s according to their relative productivity. Defining farm productivity as $s_{is} \equiv z_{is}^{1/(1-\gamma)}$, the efficient allocations with subscript e are given by:

$$k_{is}^{e} = \frac{s_{is}}{\sum_{i=1}^{F_s} s_{is}} K_s \qquad l_{is}^{e} = \frac{s_{is}}{\sum_{i=1}^{F_s} s_{is}} L_s \qquad n_{is}^{e} = \frac{s_{is}}{\sum_{i=1}^{F_s} s_{is}} N_s \qquad m_{is}^{e} = \frac{s_{is}}{\sum_{i=1}^{F_s} s_{is}} M_s.$$

It is straightforward to show that in the efficient allocation, farm output is a linear function of farm productivity $y_{is}^{e} = \frac{s_{is}}{\left[\sum_{i=1}^{F_s} s_{is}\right]^{\gamma}}[(K_s^{\alpha} L_s^{\beta} N_s^{1-\alpha-\beta})^{1-\theta} M_s^{\theta}]^{\gamma}$. As a result, aggregate output in the efficient allocation, Y_s^e, is a Cobb-Douglas aggregate of total inputs, and agricultural TFP A_s^e:

$$Y_s^e = A_s^e (F_s)^{1-\gamma}[(K_s^{\alpha} L_s^{\beta} N_s^{1-\alpha-\beta})^{1-\theta} M_s^{\theta}]^{\gamma}, \quad \text{where} \quad A_s^e = \left[\frac{1}{F_s}\sum_{i=1}^{F_s} s_{is}\right]^{1-\gamma}.$$

Following Adamopoulos et al. (2017), we define farm revenue total factor productivity (TFPR) as output per composite input, which given the production function in equation (1) is given by $y_{is}/[(k_{is}^{\alpha} l_{is}^{\beta} n_{is}^{1-\alpha-\beta})^{1-\theta} m_{is}^{\theta}]$. An important property of the efficient allocation that we exploit below is that both the marginal product of land and farm TFPR are constant across farms:

$$\text{MPL}^e_{is} = \gamma(1-\theta)\beta\frac{y^e_{is}}{l^e_{is}} = \gamma(1-\theta)\beta\frac{Y^e_s}{L_s}, \quad \text{and} \quad \text{TFPR}^e_{is} = \left[\frac{\sum_{i=1}^{F_s} s_{is}}{Y^e_s}\right]^{(1-\gamma)/\gamma}.$$

Hence, in this context, variation in marginal products of land and revenue total factor productivity is informative about distortions.

4 Rental Markets and Productivity

We start analyzing the data by characterizing the extent of rental market activity across states and providing some facts about the link between rental market activity and misallocation. Land market institutions in India are rife with frictions that potentially result in the inefficient use of land across farmers. We focus on rental market activity because sale and purchase of land remain rare in India with most land owned by households either inherited or assigned by the state. Well functioning rental markets can help in mitigating the inefficiencies in land use in the absence of markets for selling and buying land, by transferring land from low productive farmers to high productive farmers. However, rental market activity faces restrictions across all of India, with the types and degree of restrictions varying across states. We argue that the differences in legal restrictions on rental activity across states show up as differences in actual rental market activity on the ground, which leads to different agricultural outcomes across states. While it is difficult to quantify the legal restrictions on tenancy, we use the fact that there are legal differences across states to rationalize the differences in rental activity observed in the data.

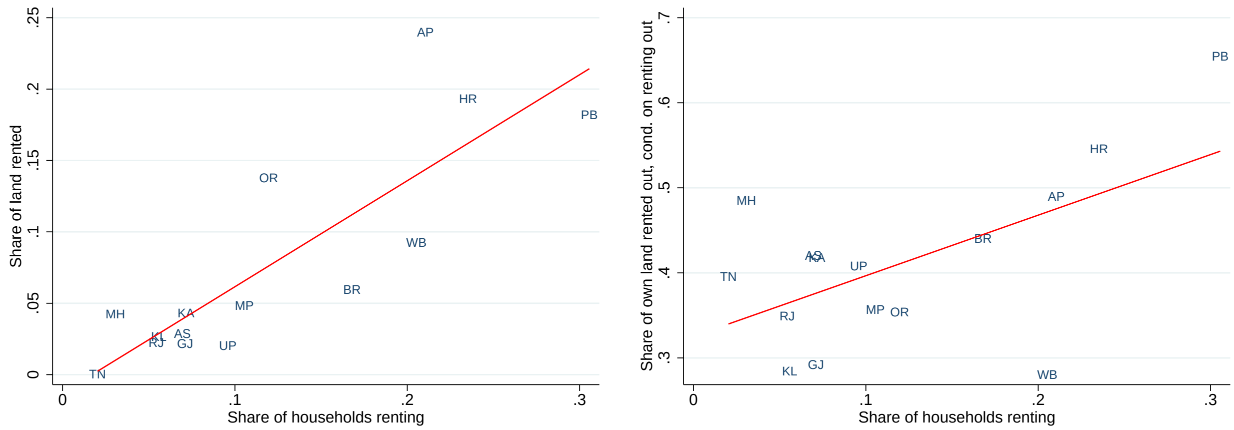
4.1 Rental Market Activity

We use the final sample of farm households to characterize the extent of rental market activity across states and over time. We define farmers as *renting-in* if they report having paid in cash for an amount of leased in land. Similarly, we define farmers as *renting-out* if they report having received cash for an amount of leased out land. Our focus is on cash rentals as a measure of rental activity. Our main reason for excluding sharecropping as a form of rentals is that tenancy regulations often do not apply to these arrangements (Besley and Burgess, 2000). Any of the empirical results presented in this section, however, are quantitatively similar when we include sharecropping, see Appendix B. A state's rental market then comprises all farmers that are either renting in or out, and a state's rental market activity is the fraction of farmers that participate in the rental market.

Across India (nationwide), 10.3% of households in our sample participate in the rental market: 3.7% of households rent out, whereas 6.7% rents in. A very small percentage of households 0.16% report both renting in and out. We count a household as renting in (out) if the amount of land rented in (out) is larger than the amount of land rented out (in). In total, 6.8% of all cultivated land in our sample is rented in.

Rental market activity differs markedly across states, as summarized in Figure 1, panel (a). In most states, such as Tamil Nadu, Kerala, Maharashtra—which represent most of India's population—less than 10% of households rent land, and less than 5% of land is rented. However, there are some states with relatively active land markets. In Punjab, 31.5% of households participate in the land rental market and 18.2% of all cultivated land is rented. Similarly, differences in rental market activity also arise along the intensive margin. For instance, Figure 1, panel (b), shows that farmers renting out land tend to transact a larger share of their owned land in states that have a larger share of land market activity. For example, in Punjab where rental market activity is high, farmers renting out, rent 65% of their land, whereas in Tamil Nadu where rental market activity is low, farmers renting out

Figure 1: Land Rental Markets in India

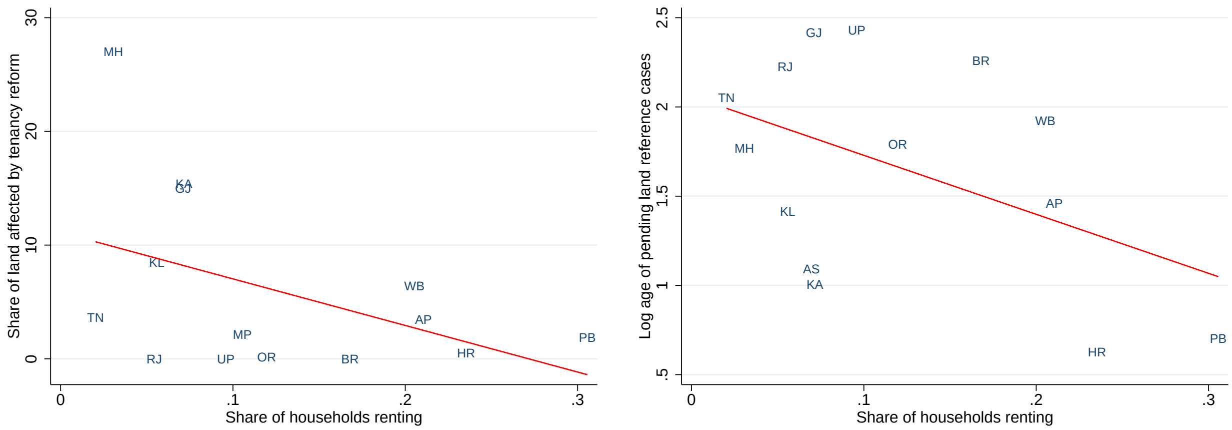


Notes: (a) Share of cultivated land rented against the share of households that participate in the rental market across states. (b) Share of own land that households rent out, conditional on renting out, against the share of households that participate in the rental market. Data is from IHDS-II.

only rent 28% of their land. We conclude that active land markets are associated with larger fractions of reallocations through land rentals.

Why are there such sizeable differences in land rental market activity across states? We emphasize two factors. First, participating in the rental market is more costly in states with more stringent tenancy regulation. We collect state-level estimates of the share of arable land transferred as a result of tenancy legislation from Kaushik and Haque (2005). Figure 2, panel (a), shows that states with higher share of land affected by tenancy reform tend to have less active land rental markets. For instance, in the state of Maharashtra, where 27% of land was transferred as a result of tenancy legislation, only 3% of households participate in the land rental market. Second, ill-defined property rights combined with weak contract enforcement raise the effective transaction costs beyond the level implied by *de jure* regulation. Following Boehm and Oberfield (2018), we collect state-level estimates of the age of pending cases that pertain to land disputes from National Judicial Data Grid (Verma, 2018) as a measure of the degree of implied land market frictions. Figure 2, panel (b), documents that states with higher rates of court congestion tend have less active land rental markets.

Figure 2: Land Reforms and Court Quality



Notes: Land rental market activity across states and (a) the share of agricultural land affected by land reforms, (b) the log age of pending land reference cases. Reform implementation data from Kaushik and Haque (2005), obtained in Deininger et al. (2009), estimates based on official data of Indian Ministry of Agriculture. Age of pending cases from National Judicial Data Grid.

4.2 Some Facts

We document suggestive evidence on the link between rental market activity and productivity. We use this evidence to motivate modeling features in our quantitative analysis in the next section.

Fact 1 *Within states, farmers renting in are more productive and own less land, whereas farmers renting out are less productive and own more land.*

Table 3, Panel A, reports the results from Probit regressions of whether a farm rents in land on (log) farm TFP and (log) endowed land. For all specifications, the result is that more productive farms are significantly more likely to expand cultivated land by renting in. The magnitude of the coefficient on farm TFP in column (1) indicates that a farm with a one standard deviation higher TFP is 19 percentage points more likely to rent in land. This finding is robust to accounting for between-state differences by introducing state fixed effects in column (2). In column (3), we consider the farm (log) land endowment (own land).

Conditional on farm TFP, a farm with a one standard deviation higher land endowment is 17 percentage points less likely to rent in. The magnitude of the coefficients on TFP and land endowment barely change when accounting for individual demographic and land quality controls in columns (4) and (5). Demographic controls include a farm operator's age, gender, years of education, and whether the farm operator is literate or not. Land quality controls include the share of cultivated land that is irrigated, and the share of cultivated land that is used for orchard production.

Table 3, Panel B, reports the results of Probit regressions on whether a farm rents out land on farm TFP and land endowment. Conditional on the land endowment, farmers that rent out are significantly *less* productive; a one standard deviation higher TFP is associated with a 15 percentage points lower probability of renting out. Farmers with a one standard deviation higher land holding are 42 percentage points more likely to rent out. These coefficients increase to 19% and 43% after accounting for demographic and land quality controls, respectively.[8]

Fact 2 *States with more active rental markets have less dispersed marginal products of land across farms.*

Table 4, Panel A, reports the results from regressions of farm absolute deviations of (log) marginal product of land from the state mean on the share of farms participating in the rental market in the state. The results indicate that states with more active rental markets, marginal products of land are significantly less dispersed. The relationship remains strong and significant after accounting for farm TFP, demographic characteristics, land quality, and state-level controls in columns (2) to (5).

Table 4, Panel B, reports the results from regressions of a farm's absolute deviation of log

[8]Note that since we do not observe productivity of farmers who rent out all their land, they are excluded from the empirical analysis, however, if these are low productivity households then our findings are an under-estimate.

Table 3: Determinants of Rental Market Activity

Panel A: Dependent variable is whether a farm rents in land or not	(1) Probit	(2) Probit	(3) Probit	(4) Probit	(5) Probit
TFP (log)	0.188***	0.199***	0.294***	0.305***	0.295***
	(0.0355)	(0.0394)	(0.0512)	(0.0528)	(0.0556)
Own land (log)			-0.181***	-0.170***	-0.168***
			(0.0396)	(0.0405)	(0.0394)
State FE	N	Y	Y	Y	Y
Demographic controls	N	N	N	Y	Y
Land quality controls	N	N	N	N	Y
Observations	8359	8359	8359	8359	8359
R^2	0.0192	0.1019	0.1148	0.1213	0.1220

Panel B: Dependent variable is whether a farm rents out land or not	(1) Probit	(2) Probit	(3) Probit	(4) Probit	(5) Probit
TFP (log)	0.0590**	0.0633**	-0.150***	-0.159***	-0.189***
	(0.0272)	(0.0261)	(0.0416)	(0.0374)	(0.0361)
Own land (log)			0.415***	0.411***	0.428***
			(0.0570)	(0.0584)	(0.0614)
State FE	N	Y	Y	Y	Y
Demographic controls	N	N	N	Y	Y
Land quality controls	N	N	N	N	Y
Observations	8359	8359	8359	8359	8359
R^2	0.0019	0.0457	0.1065	0.1196	0.1262

Notes: Standard errors in parentheses, clustered by state. We standardize log TFP and log owned land within states. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$

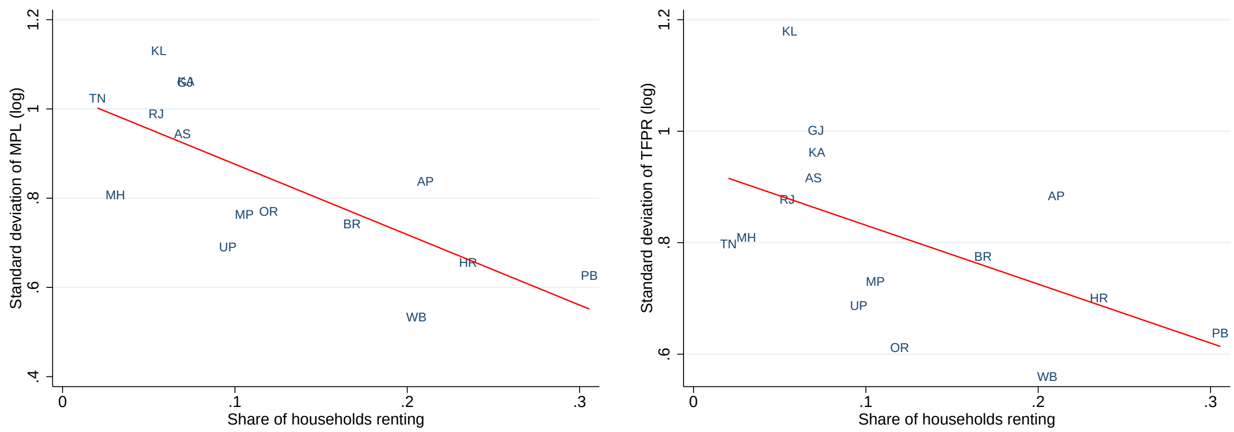
Table 4: Rental Market Activity and Misallocation

Panel A: Dependent variable is absolute deviation of (log) marginal product of land from state mean					
	(1)	(2)	(3)	(4)	(5)
	OLS	OLS	OLS	OLS	OLS
Share hh renting	-1.439***	-1.439***	-1.441***	-1.216***	-1.092***
	(0.362)	(0.362)	(0.360)	(0.351)	(0.324)
TFP (log)		-0.0155*	-0.0165*	-0.0103	-0.0134
		(0.00800)	(0.00900)	(0.00819)	(0.00822)
Demographic controls	N	N	Y	Y	Y
Land quality controls	N	N	N	Y	Y
State-level controls	N	N	N	N	Y
Observations	8617	8617	8617	8617	8617
R^2	0.028	0.029	0.029	0.038	0.051

Panel B: Dependent variable is absolute deviation of (log) TFPR from state mean					
	(1)	(2)	(3)	(4)	(5)
	OLS	OLS	OLS	OLS	OLS
Share hh renting	-0.914***	-0.914***	-0.915***	-0.731**	-0.627*
	(0.297)	(0.297)	(0.291)	(0.295)	(0.301)
TFP (log)		-0.00275	-0.00588	-0.00175	-0.00168
		(0.00654)	(0.00836)	(0.00886)	(0.00832)
Demographic controls	N	N	Y	Y	Y
Land quality controls	N	N	N	Y	Y
State-level controls	N	N	N	N	Y
Observations	8617	8617	8617	8617	8617
R^2	0.013	0.013	0.016	0.024	0.034

Notes: Standard errors in parentheses, clustered by state. We standardize log TFP and log owned land within states. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$

Figure 3: Rental Market Activity and Misallocation



Notes: Panel (a) reports the standard deviation of (log) farm-level MPL and panel (b) the standard deviation of (log) TFPR both with respect to the share of households renting in each state.

TFPR from the state mean on the share of households participating in a state's rental market. States with more active rental markets have significantly lower dispersion of log TFPR. Again, these findings are robust to a host of farmer- and state-level controls in columns (2)-(5).

Figure 3 summarizes these results at the state level. Panel (a) documents a robust negative relationship between the state-level standard deviation of the log marginal product of land and the share of households participating in the renal market. Panel (b) documents a negative relationship between the state-level dispersion in log TFPR and rental market activity.

Fact 3 *States with more active rental markets have more efficient land reallocations over time, i.e., land reallocates from less to more productive farms.*

We construct a measure of the reallocation potential of a farmer i in state s and wave t, as the ratio between the efficient to actual amount of operated land (l^e_{ist}/l_{ist}) where l^e_{ist} is the efficient land allocation derived in Section 3.2.

Table 5: Land Reallocation and Rental Markets

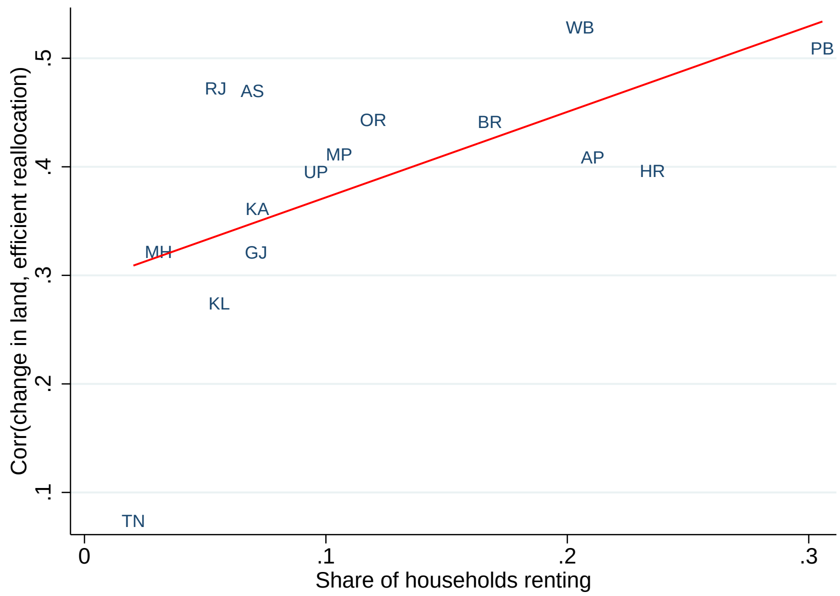
Dependent variable is change in (log) cultivated land between waves I and II	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS
Reallocation potential wave I	0.272***	0.231***	0.175***	0.177***	0.161***
	(0.0272)	(0.0498)	(0.0323)	(0.0327)	(0.0344)
Reallocation potential wave I x Share hh renting		0.473	1.042***	1.039***	1.079***
		(0.389)	(0.255)	(0.249)	(0.246)
State FE	N	N	Y	Y	Y
Demographic controls	N	N	N	Y	Y
Land quality controls	N	N	N	N	Y
Observations	8617	8617	8617	8617	8617
R^2	0.151	0.152	0.217	0.220	0.228

Notes: Standard errors in parentheses, clustered by state. We standardize log TFP and log owned land within states. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table 5 shows regressions of a farmer's change in cultivated land between the two waves on its (log) reallocation potential in wave I. Throughout, the reallocation potential is a strong and robust predictor of the change in the amount of cultivated land, which could be suggestive of nation-wide efficiency increasing over time. In columns (2)-(5) we introduce an interaction term between a farmer's reallocation potential and the rental market activity in its state. After accounting for between-state differences in aggregate changes in land (column (3)) the interaction term is positive and significant, indicating that land is reallocated more efficiently in states with more active rental markets. This coefficient changes little when accounting for demographic and land quality characteristics at the farm-level in columns (4) and (5).

Figure 4 summarizes the result land is reallocated more efficiently in states with more active rental markets by reporting the within-state correlation between a farmer's change in cultivated land and its reallocation potential. In line with the farm-level results in Table 5, land is reallocated more towards farmers farther from their efficient allocation in states with higher levels of rental market activity. The evidence suggests a strong link between rental market activity and a more efficient allocation of resources across farmers, potentially contributing to agricultural productivity differences across states.

Figure 4: Land Reallocation and Rental Market Activity



Notes: The correlation between farm-level change in cultivated land and reallocation potential in wave I and the share of households participating in the rental market across states. Data from IHDS-I and IHDS-II.

5 Model

To assess the quantitative relevance of rental market activity on agricultural productivity in Indian states, we develop a model of agricultural production based on heterogeneous farms and distorted rental markets building on Deininger and Nagarajan (2010) and Adamopoulos and Restuccia (2014).

5.1 Description

We consider an agricultural economy that consists of S regions called states indexed by s. Each state s is endowed with an aggregate amount of land L_{st} and a finite number of farm households F_{st} indexed by i that differ in their farming productivity z_{ist} and land endowment $\bar{l}_{ist}$. There is no trade or factor mobility between states. In what follows, we drop time subscripts for ease of exposition.

Individual farms produce a homogeneous output good and we normalize the price of the output good to one. We assume that endowed land cannot be sold so that land reallocation occurs only through rentals. While this assumption may seem restrictive, in practice there are very few land sale transactions. In our final sample, only 3% of farming households purchased the land they own, 95% of them acquired the land through family. In contrast, about 10% of farming households participate in the rental market in either wave. Farmers can rent land to (l_{is}^{out}) or from (l_{is}^{in}) other farmers, but face farm-specific transaction costs q_{is}^{in} and q_{is}^{out} per unit of land. For simplicity, we model farm-specific costs as taxes on the rental market price of land q_s, which we denote as τ_{is}^{in} and τ_{is}^{out}, but clearly in practice these taxes stand-in for a myriad of explicit and implicit regulations that affect land transactions.

We focus on the institutions that affect land rental markets across states and model the effect of these institutions through land wedges. We argue that an appropriate approach to capture the effect of these institutions on farm decisions is to have land wedges impact all other inputs so that input ratios are unaffected. It is straightforward to show that this approach is equivalent to modelling land as a composite input in production since all the input ratios are constant. The evidence from many different contexts is consistent with this assumption (Hsieh and Klenow, 2009; Restuccia and Santaeulalia-Llopis, 2017; Adamopoulos et al., 2017; Chen et al., 2017), in particular, we note that in our data, the variation in input ratios across farms only account for 30 percent of the productivity gains of reallocation in the data. To the extent that this variation may be due to technology differences across farmers, we abstract from this source of variation in our analysis. Furthermore, as discussed in Section 2, legal access to land is an essential requirement for farmers in India to access institutional credit and other farm benefits. Frictions to accessing land would then show up as frictions on other factors of production as well. We follow this approach in specifying the model below.

5.2 Decentralized Allocation

Given farm productivity z_{is}, land endowment $\bar{k_i s}$, prices and wedges, a farm chooses the amount of cultivated land l_{is}, which is the sum of land rented in l_{is}^{in} and the amount of owned land that is not rented out $\bar{l}_{is} - l_{is}^{out}$, to maximize profits:

$$\max_{\{l_{is}, l_{is}^{out}, l_{is}^{in} \geq 0\}} \pi_{is} \equiv z_{is} l_{is}^{\gamma} - q_s[(1 + \tau_{is}^{in}) l_{is}^{in} + (1 + \tau_{is}^{out})(\bar{l}_{is} - l_{is}^{out})], \tag{3}$$

subject to

$$l_{is} = \bar{l}_{is} + l_{is}^{in} - l_{is}^{out}.$$

We can contrast this problem with the standard heterogeneous farm model (e.g., Adamopoulos et al., 2017) in which farms do not choose *how* they participate in the market for land, but only the total amount of cultivated land l_{is}, for which they pay a farm-specific price $q_{is} = q_s(1 + \tau_{is})$. Using the definition of cultivated land and the two problems, we can express this price as:

$$q_{is} = q_{is}^{out} \frac{\bar{l}_{is} - l_{is}^{out}}{l_{is}} + q_{is}^{in} \frac{l_{is}^{in}}{l_{is}}.$$

The rental price of land is thus the weighted average of the price of renting in land and renting out, with weights equal to the shares of cultivated land owned and rented in. As a result, the land wedge is the weighted average of wedges for renting in land and renting out:

$$(1 + \tau_{is}) = (1 + \tau_{is}^{out}) \frac{\bar{l}_{is} - l_{is}^{out}}{l_{is}} + (1 + \tau_{is}^{in}) \frac{l_{is}^{in}}{l_{is}}.$$

The typical approach in the misallocation literature is to infer the producer wedge as that required to rationalize the observed producer allocation as an equilibrium outcome given the producer productivity. In this context, only producer productivity and operational land are required. Our approach exploits the additional information that is provided on the amount of land owned and operated, with rented land as the vehicle for the separation between owned and operated land. This allows us to characterize in more detail the distortions to rental markets and to assess the contribution of observed land rental activity for productivity differences across states in India.

Within a state, farm-specific rental prices $\{q_{is}^{in}, q_{is}^{out}\}_{i=1}^{F_s}$ rationalize the observed farm land choices $\{l_{is}, l_{is}^{in}, l_{is}^{out}\}_{i=1}^{F_s}$. This allocation can be summarized as:

$$q_s(1+\tau_{is}^{in}) \geq MPL_{is} = q_s(1+\tau_{is}^{out}) \qquad \text{if } l_{is}^{in} = 0 \text{ and } l_{is}^{out} > 0, \tag{4}$$

$$q_s(1+\tau_{is}^{in}) = MPL_{is} \geq q_s(1+\tau_{is}^{out}) \qquad \text{if } l_{is}^{in} > 0 \text{ and } l_{is}^{out} = 0, \tag{5}$$

$$q_s(1+\tau_{is}^{in}) \geq MPL_{is} \geq q_s(1+\tau_{is}^{out}) \qquad \text{if } l_{is}^{in} = 0 \text{ and } l_{is}^{out} = 0, \tag{6}$$

where $MPL_{is} = \gamma \frac{y_{is}}{l_{is}}$ is the marginal product of land of farm i in state s.

A *competitive equilibrium* is a set of prices $\{q_s, \tau_{is}^{in}, \tau_{is}^{out}\}$ and allocations $\{l_{is}, l_{is}^{in}, l_{is}^{out}\}$ such that: (i) Given prices, farmers' allocations maximize profits, i.e., solve the problem in equation (3), and (ii) the land market clears, i.e., $\sum_i l_{is} = \sum_i \bar{l}_{is}$. Appendix C describes the procedure we use to solve the competitive equilibrium in each state.

5.3 Estimating Land-Market Distortions

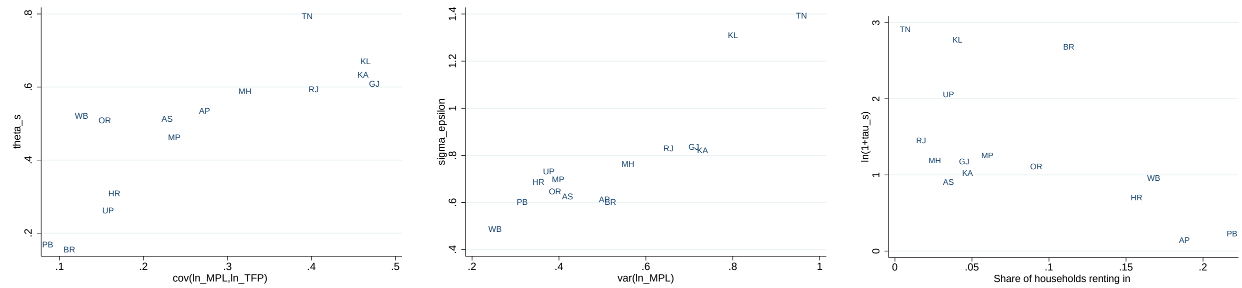
In order to estimate state-specific land-market distortions from available data, we impose the following restrictions: $(1+\tau_{is}^{in}) = (1+\tau_{is}^{l})$ and $(1+\tau_{is}^{out}) = (1+\tau_{is}^{l})(1+\tau_s)^{-1}$, where $(1+\tau_{is}^{l})$ is a farm-specific wedge, and $(1+\tau_s)$ is a state-specific distortion, common across farms within a state, that drives a wedge between the cost of renting in and the returns to renting out, thus $(1 + \tau_s)$ can be interpreted as a state-wide land transaction tax that is borne by the lessor. Our results are isomorphic to the case in which the tax burden is shared with the lessee.

Furthermore, we impose the following parametric assumptions about farm idiosyncratic distortions: $\ln(1 + \tau^l_{is}) = \kappa_s + \theta_s \ln z_{is} + \epsilon_{is}$, where $\epsilon_{is} \sim N(0, \sigma^2_{\epsilon,s})$, *i.i.d.* across farms. This parameterization is known to generate a good fit with distortions data (Restuccia and Rogerson, 2017; Restuccia, 2019). The parameter κ_s is a constant that we normalize to zero in our empirical estimation of wedges since it cannot be distinguished from τ_s. However, this parameter becomes relevant when decomposing the contributions of idiosyncratic versus state-wide features of distortions in the counterfactuals as we discuss below.

Under these assumptions, the farm choice problem in equations (4) to (6) can be solved to construct three moments that depend on the three unknowns (τ_s,θ_s,$\sigma^2_{\epsilon,s}$) and use the data counterpart of these moments to estimate the distortions parameters. The moments we construct are: (1) the covariance between the marginal product of land and productivity across farmers, (2) the variance of the marginal product of land across farmers, and (3) the share of farmers renting. Figure 5 reports the estimated parameter values for θ_s, $\sigma^2_{\epsilon,s}$, and $\ln(1 + \tau_s)$ against the respective moments that provide their identification in the data across states. We provide more details on this procedure and the motivation for our choice of specific moments in Appendix D.

Table 6 summarizes the moments we use for each state in estimating land market distortions and the resulting estimated parameter values. As discussed earlier, states differ substantially in the observed dispersion of the marginal product of land across farms and its relationship with farm productivity which are indicative of distortions and misallocation. For instance, many states have more than double the dispersion in the marginal product of land across farms relative to Punjab, and the higher dispersion is systematically related with farm pro-

Figure 5: Identification of Rental-Market Distortions



Notes: Panel (a) reports the estimated θ_s against state variation in the covariance between log marginal product of land and farm productivity. Panel (b) reports the estimated σ_s against state differences in the variance of log marginal product of land. Panel (c) reports the estimated state-level rental wedge $\ln(1+\tau_s)$ against variation in the share of households renting in.

ductivity, unlike in Punjab where the covariance of farm productivity and land productivity is fairly low. Moreover, these patterns are strongly associated with the extent of rental markets in the state. These patterns translate into substantial differences in idiosyncratic distortions and state-level wedges as shown in the last three columns of Table 6.

To appreciate the systematic pattern of land distortions and the extent of land markets across sates, Figure 6 reports the estimated parameters of distortions $(\theta_s, \sigma_{\epsilon,s}, \tau_s)$ for each state against the share of farmers renting. Land distortions are less severe in states with more active land markets, for instance the estimates for θ_s range from 0.77 in Andhra Pradesh to 0.17 in Punjab. This wide range is consistent with evidence of high correlation in other developing countries such as China, Malawi, and Uganda where land markets are severely restricted and of low correlation in developed countries such as the United States (Restuccia and Santaeulalia-Llopis, 2017; Adamopoulos et al., 2017; Chen et al., 2017; Aragon et al., 2019). Note that the estimate of $\sigma_{\epsilon,s}$ is not systematically different across states, which implies that most of the variation in idiosyncratic land distortions are reflected in the systematic component as land frictions tend to systematically constrain the more productive farmers that would like to expand. We also observe a systematic relationship between state-level land frictions and the share of farms renting.

Table 6: Targeted Moments and Estimated Parameters across Indian States

	Targeted moments			Estimated parameters		
	Covariance (lnMPL, lnTFP)	Variance (lnMPL)	Share renting in	θ_s	σ_s^2	$\ln(1+\tau_s)$
India	0.28	0.56	0.17	0.48	0.57	1.32
State:						
Andhra Pradesh (AP)	0.27	0.50	0.19	0.54	0.38	0.14
Assam (AS)	0.23	0.42	0.04	0.51	0.39	0.91
Bihar (BR)	0.11	0.52	0.12	0.15	0.36	2.68
Gujarat (GJ)	0.48	0.71	0.04	0.61	0.70	1.18
Haryana (HR)	0.17	0.35	0.16	0.31	0.47	0.70
Karnataka (KA)	0.46	0.73	0.05	0.63	0.68	1.03
Kerala (KL)	0.46	0.80	0.03	0.67	1.72	2.77
Madhya Pradesh (MP)	0.24	0.40	0.06	0.46	0.49	1.25
Maharashtra (MH)	0.32	0.56	0.03	0.59	0.58	1.19
Orissa (OR)	0.15	0.39	0.09	0.51	0.42	1.11
Punjab (PB)	0.09	0.32	0.23	0.17	0.36	0.23
Rajasthan (RJ)	0.40	0.65	0.02	0.59	0.69	1.45
Tamil Nadu (TN)	0.39	0.96	0.01	0.79	1.94	2.91
Uttar Pradesh (UP)	0.16	0.38	0.04	0.26	0.54	2.06
West Bengal (WB)	0.13	0.25	0.17	0.52	0.24	0.96

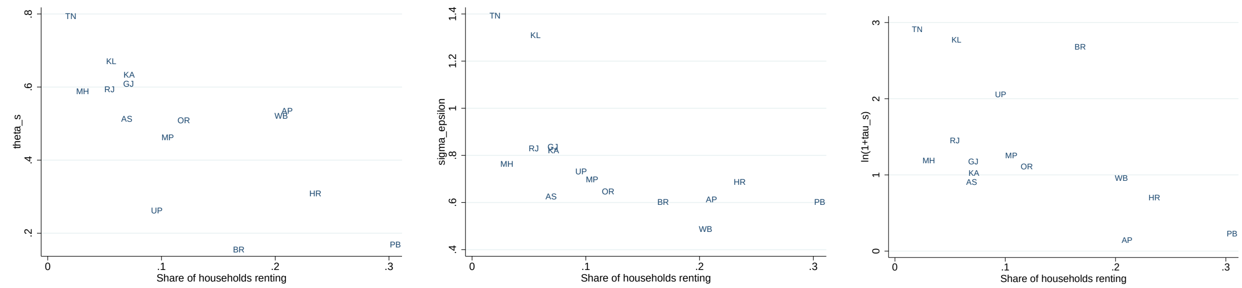
Notes: Moments used as targets in model estimation and estimated parameter values by state. The moments are: (1) the covariance of (log) marginal product of land and (log) permanent TFP across farmers, (2) the variance of (log) marginal product of land across farmers, and (3) the share of farmers renting in (some of) their operated land. Values for India are sample means, weighed by farmers per state.

5.4 Model Fit

We have taken a parametric approach to capturing land market distortions in the data, in particular, we have summarized land market distortions with three parameters: the slope and variance of farm-specific distortions and a state-level wedge to rentals. This parsimonious approach successfully captures the disaggregated patterns of actual land allocations across states.

Figure 7 reports the share of cultivated land by each farmer as a proportion of total cultivated land in the state, for all farmers in India, both in the estimated model as well as in the micro

Figure 6: Land Distortions across Indian States

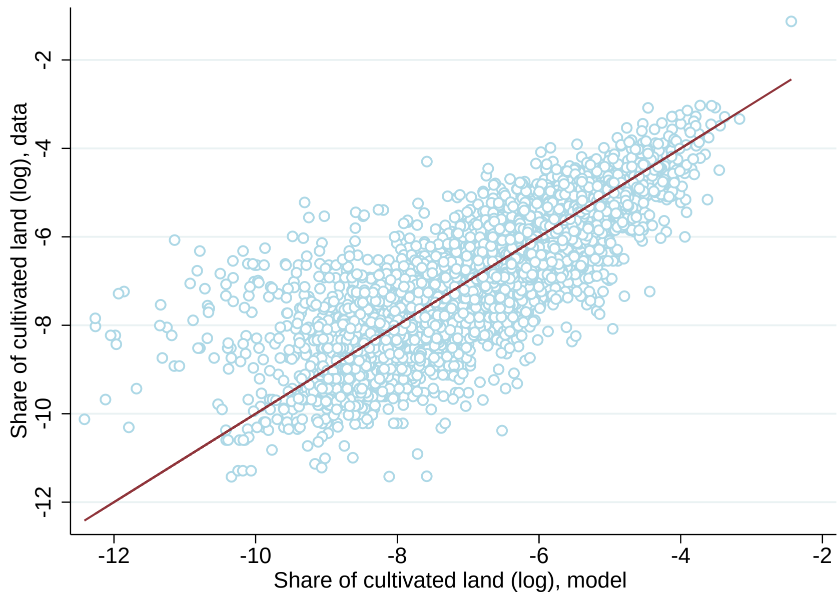


Notes: Estimated parameters of distortions against the share of farmers renting in each state. Panel (a) plots the estimated elasticity of land distortions with respect to productivity across farmers θ_s, panel (b) plots the estimated standard deviation of unsystematic idiosyncratic distortions, $\sigma_{\epsilon,s}$, and panel (c) plots state-level land wedges $\ln(1+\tau_s)$.

data, characterizing the overall fit of the model for the allocation of land across farms. The (red) line represents the 45 degree line which would be a perfect fit of the model to the data and the (light blue) circles represent farms in the model and data. Note that despite the limited parameters imposed in the model, the estimates provide a fairly good fit of the land allocations in the data, with the circles closely around the 45 degree line.

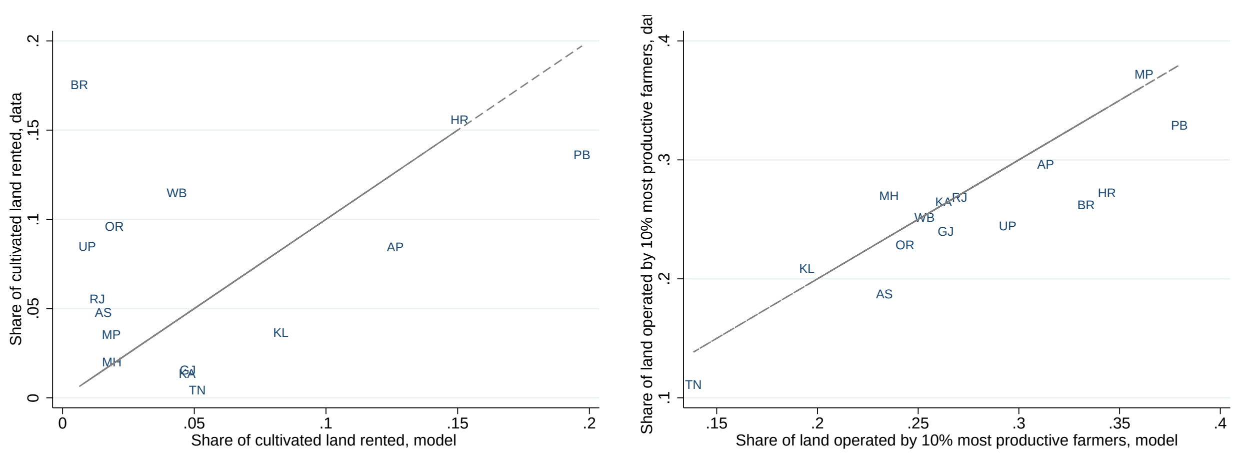
Table 7, first column, provides a summary statistic of the fit of land allocations for each state, by reporting the correlation between farm-level land shares in the model and the data, a correlation hovering 80 percent for most states. The table also reports the share of rented land in each state. While the model does not match the share of rented land in each state exactly (recall that the estimation only targets the share of farmers renting in), the model captures the overall pattern of differences in rented land across states (Figure 8, panel a). Importantly, the model matches well the share of cultivated land among the most productive farms (Figure 8, panel b, documents the share of cultivated land among the 10 percent most productive farms in the model and data). Similarly, Table 8 shows a fairly good fit for other subsets of farms in the productivity distribution such as the 25 and 5 percent most productive farms.

Figure 7: Land Allocations in the Model and Data, All Indian States



Notes: Cultivated land by farms relative to total cultivated land in the state in the model (unweighted average of 100 simulations) and data. The red line represents the 45 degree line.

Figure 8: Rented Land and Concentration among Productive Farmers, Model and Data



Notes: Panel (a) reports the share of rented land in each state in the model and the data. Panel (b) reports the share of cultivated land operated by the 10% most productive farmers in each state in the model and the data. The model is an unweighed average of 100 simulations. Dashed line corresponds to the 45 degree line.

Table 7: Land Allocations and Rented Land, Model and Data

	Correlation of Land Allocations	Share of Rented Land	
	Model and Data	Data	Model
India:	0.82	0.06	0.04
State:			
Andhra Pradesh (AP)	0.55	0.08	0.13
Assam (AS)	0.64	0.05	0.02
Bihar (BR)	0.63	0.18	0.01
Gujarat (GJ)	0.80	0.02	0.05
Haryana (HR)	0.75	0.16	0.15
Karnataka (KA)	0.80	0.01	0.05
Kerala (KL)	0.84	0.04	0.08
Madhya Pradesh (MP)	0.84	0.04	0.02
Maharashtra (MH)	0.83	0.02	0.02
Orissa (OR)	0.67	0.10	0.02
Punjab (PB)	0.77	0.14	0.20
Rajasthan (RJ)	0.81	0.06	0.01
Tamil Nadu (TN)	0.76	0.01	0.05
Uttar Pradesh (UP)	0.81	0.08	0.01
West Bengal (WB)	0.77	0.11	0.04

Notes: Column (1) reports the correlation between the share of land cultivated by a farmer in the data and the model for each state. Columns (2) and (3) report the share of rented land in each state. The model refers to the unweighed average of 100 simulations. The land shares for India are sample means, weighed by farmers per state.

Table 8: Concentration of Land among Most Productive Farmers

	Share of Land Operated By Most Productive					
	25%		10%		5%	
	Data	Model	Data	Model	Data	Model
India:	0.49	0.50	0.27	0.28	0.17	0.18
State:						
Andhra Pradesh (AP)	0.45	0.53	0.30	0.31	0.17	0.19
Assam (AS)	0.36	0.43	0.19	0.23	0.10	0.16
Bihar (BR)	0.47	0.57	0.26	0.33	0.16	0.21
Gujarat (GJ)	0.50	0.50	0.24	0.26	0.13	0.15
Haryana (HR)	0.49	0.57	0.27	0.34	0.19	0.24
Karnataka (KA)	0.49	0.49	0.26	0.26	0.17	0.16
Kerala (KL)	0.42	0.39	0.21	0.19	0.11	0.10
Madhya Pradesh (MP)	0.58	0.57	0.37	0.36	0.25	0.24
Maharashtra (MH)	0.48	0.45	0.27	0.24	0.13	0.14
Orissa (OR)	0.42	0.45	0.23	0.24	0.14	0.15
Punjab (PB)	0.57	0.62	0.33	0.38	0.20	0.24
Rajasthan (RJ)	0.48	0.48	0.27	0.27	0.17	0.16
Tamil Nadu (TN)	0.22	0.29	0.11	0.14	0.04	0.07
Uttar Pradesh (UP)	0.50	0.55	0.24	0.29	0.16	0.19
West Bengal (WB)	0.47	0.47	0.25	0.25	0.14	0.15

Notes: Share of operated land by the 25/10/5% most productive farms the data and model. The model is an unweighed average of 100 simulations. Values for India are sample means, weighed by farmers per state.

5.5 Counterfactuals

Given our estimates of land market distortions for each state, we now explore a series of counterfactuals aimed at assessing the aggregate consequences of land market frictions. Starting from the baseline calibrated model in each state we study the following counterfactuals: "Efficient" is the counterfactual efficient allocation of land and "No idiosyncratic" is the counterfactual when there are no idiosyncratic distortions, that is when $\sigma^2_{\epsilon,s} = \theta_s = 0$. For this counterfactual, we pivot the slope of distortions around the same mean, that is we set θ_s to zero and increase κ_s to keep the same average wedges in each state. Recall that the constant κ_s was normalized to zero in the baseline calibration. The gap between the efficient and the no idiosyncratic distortions counterfactuals (the ratio of efficient to no idiosyncratic) reflects the residual role of state-level land distortions τ_s. We also study a counterfactual where we assume no rentals relative to the baseline model. Hence, this counterfactual assesses the importance of actual rentals in the data in each state as reflected in our baseline calibrated model.

Table 9 reports the results of each counterfactual for agricultural TFP in each state (panel A) and relative to Punjab (panel B). The table also reports the results for the average of India. We emphasize the following results. First, actual land rentals across states in India contribute substantially to agricultural TFP in each state, that is, no land rentals reduces agricultural TFP by 22 percent in average and by as much as 37 percent in some states such as Assam. This implies that in the absence of land rentals, differences in agricultural productivity across states in India would be even larger that those documented earlier (see also Figure 9, panel a). Relative to Punjab, differences in agricultural productivity across states would be 16 percent larger in the absence of land rentals. Even the admittedly limited land rental markets in India contribute substantially to agricultural productivity.

Second, eliminating land distortions to achieve an efficient allocation of resources would produce a substantial increase in agricultural productivity, especially among the least productive states, providing an important convergence in agricultural productivity across states (Figure 9 panel b). An efficient allocation of land would increase agricultural productivity by 29 percent on average, 13 percent relative to Punjab; but for some states the increase is much larger, 53, 47, and 45 percent in Tamil Nadu, Karnataka, and Kerala (33, 28, and 27 percent relative to Punjab). As a benchmark for comparison, considering the effect on the share of labor in agriculture associated with changes in agricultural TFP, a 30 percent increase in agricultural TFP translates into a 56 percent increase in agricultural labor productivity, erasing about a third of the difference in agricultural productivity between the least productive states and Punjab documented in Table 2.

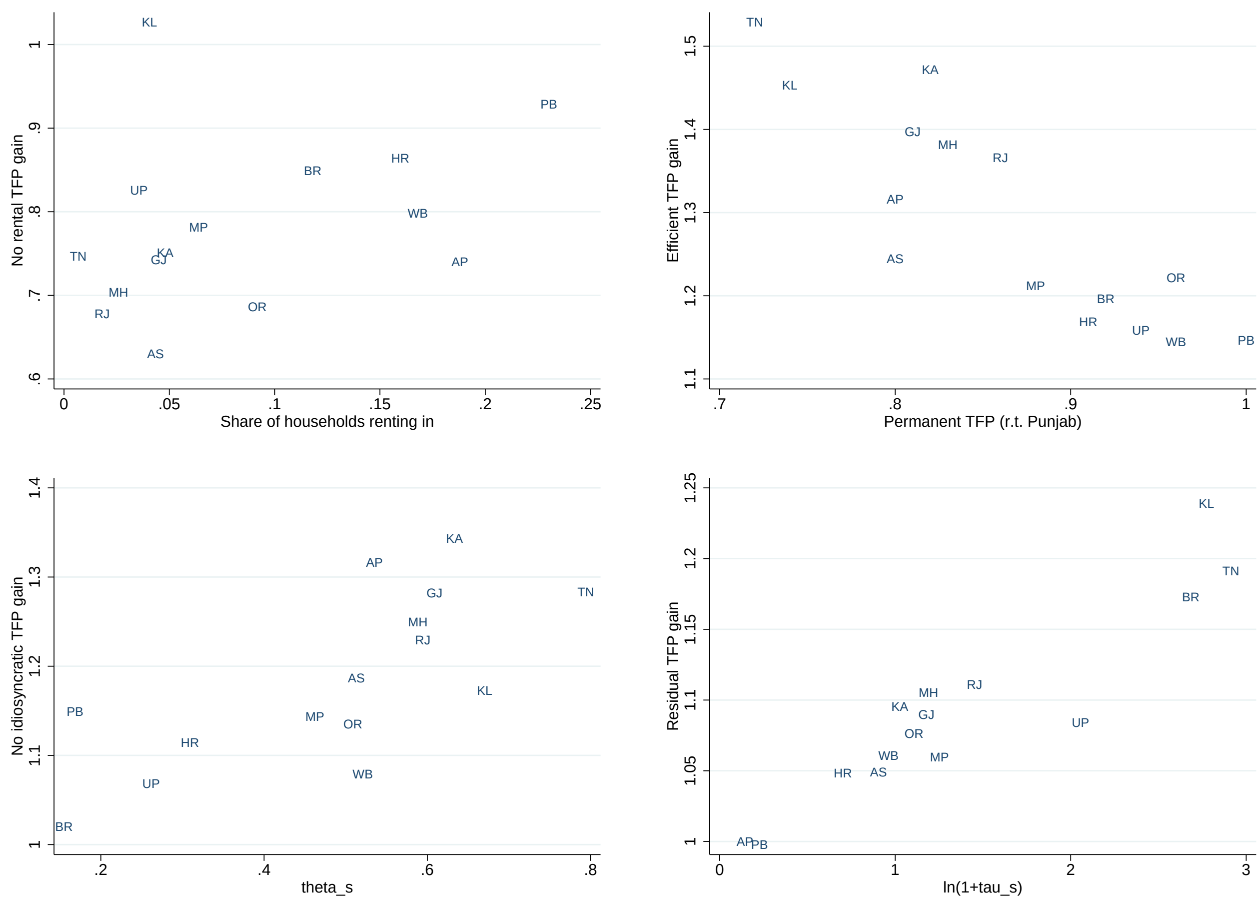
Third, idiosyncratic distortions (farm-specific distortions) contribute substantially to depress

Table 9: Counterfactual Agricultural TFP relative to Baseline Model

Panel A: Absolute values, baseline model=1				
	No rentals	Efficient	No idiosyncratic	Residual
India:	0.78	1.29	1.18	1.09
State:				
Andhra Pradesh (AP)	0.74	1.32	1.32	1.00
Assam (AS)	0.63	1.24	1.19	1.04
Bihar (BR)	0.85	1.20	1.02	1.18
Gujarat (GJ)	0.74	1.40	1.28	1.09
Haryana (HR)	0.86	1.17	1.11	1.05
Karnataka (KA)	0.75	1.47	1.34	1.10
Kerala (KL)	1.03	1.45	1.17	1.24
Maharashtra (MH)	0.70	1.38	1.25	1.10
Madhya Pradesh (MP)	0.78	1.21	1.14	1.06
Orissa (OR)	0.69	1.22	1.14	1.07
Punjab (PB)	0.93	1.15	1.15	1.00
Rajasthan (RJ)	0.68	1.37	1.23	1.11
Tamil Nadu (TN)	0.75	1.53	1.28	1.20
Uttar Pradesh (UP)	0.83	1.16	1.07	1.08
West Bengal (WB)	0.80	1.14	1.08	1.06
Panel B: Values relative to Punjab, baseline model=1				
	No rentals	Efficient	No idiosyncratic	Residual
India:	0.84	1.13	1.03	1.10
State:				
Andhra Pradesh (AP)	0.80	1.15	1.15	1.00
Assam (AS)	0.68	1.09	1.03	1.06
Bihar (BR)	0.91	1.04	0.89	1.17
Gujarat (GJ)	0.80	1.22	1.12	1.09
Haryana (HR)	0.93	1.02	0.97	1.05
Karnataka (KA)	0.81	1.28	1.17	1.09
Kerala (KL)	1.11	1.27	1.02	1.25
Maharashtra (MH)	0.76	1.21	1.09	1.11
Madhya Pradesh (MP)	0.84	1.06	1.00	1.06
Orissa (OR)	0.74	1.07	0.99	1.08
Punjab (PB)	1.00	1.00	1.00	1.00
Rajasthan (RJ)	0.73	1.19	1.07	1.11
Tamil Nadu (TN)	0.80	1.33	1.12	1.19
Uttar Pradesh (UP)	0.89	1.01	0.93	1.09
West Bengal (WB)	0.86	1.00	0.94	1.06

Notes: Agricultural TFP relative to baseline model, panel A absolute values, panel B relative to Punjab. In "No rentals" each farm operates their owned land. "Efficient" is when $\sigma^2_{\epsilon,s} = \theta_s = \tau_s = 0$. "No idiosyncratic" is when $\sigma^2_{\epsilon,s} = \theta_s = 0$. Residual is the ratio of Efficient to No idiosyncratic counterfactuals and reflects the contribution of state-level land wedges τ_s. Values for India are sample means, weighed by farmers per state. Permanent TFP constructed using the estimated permanent (farm fixed effect) measure of farm TFP.

Figure 9: Counterfactual Agricultural TFP



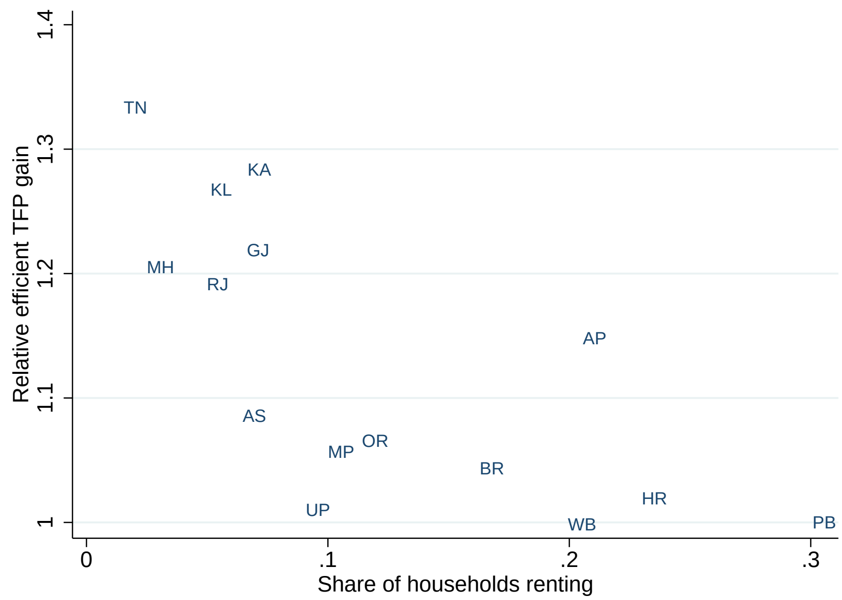
Notes: Agricultural TFP in each counterfactual relative to the baseline model. In "No rentals" farms operate their owned land. "Efficient" sets $\sigma^2_{\epsilon,s} = \theta_s = \tau_s = 0$. "No idiosyncratic" sets $\sigma^2_{\epsilon,s} = \theta_s = 0$. Residual is the ratio of Efficient to No idiosyncratic counterfactuals and reflects the effect of state-level land wedges τ_s.

agricultural productivity. For instance, on average eliminating idiosyncratic distortions increases agricultural TFP by 18 percent compared to 29 percent in the efficient allocation. As a result, idiosyncratic distortions contribute to two thirds of the reallocation gains from eliminating distortions ($\ln(1.18)/\ln(1.29)$). Nevertheless, our finding is that state-specific land distortions are also significant, contributing more than one third of the average reallocation gains ($\ln(1.09)/\ln(1.29)$), almost 60 percent in the state of Kerala. Figure 9, panel d, documents the positive relationship between the TFP gain in the no idiosyncratic distortions counterfactual and the elasticity of distortions θ_s. Panel d in Figure 9 show a positive relationship between the TFP gains in Residual against state-level land wedges $\ln(1 + \tau_s)$.

We also find that the gains across states from an efficient reallocation of land are systematically related to the extent of rental markets, the largest TFP gains are in states with the least active rental markets. This pattern is documented in Figure 10 where we report the gains from an efficient reallocation of land against the share of farmers renting in the data.

Table 10 reports other statistics for each counterfactual relative to the benchmark model in order to illustrate the channels through which land distortions affect aggregate agricultural TFP. We focus on two statistics on the extent of rental markets: the share of farms renting (panel A) and the share of land operated by the most productive farms (panel B). The efficient allocation implies an almost doubling of the share of farms renting for India on average, whereas eliminating idiosyncratic distortions has almost no effect on the extensive margin of rental market activity, instead, all of the increase in the share of farms renting in the efficient allocation is due to state-level wedges τ_s (Residual column compared with Efficient counterfactual in panel A). This implies that state-level land wedges account for most of the extensive margin effect of rental markets. In the efficient allocation, the share of land operated by the 10 percent most productive farms more than doubles, from 27 percent in the baseline model to 62 percent. Eliminating idiosyncratic distortions has a substantial effect on this share in most states, with state-level wedges being as important or more

Figure 10: Rental Markets and Relative Agricultural TFP Gains across States



Notes: Agricultural TFP gains are the aggregate productivity gains from an efficient allocation of resources in each state relative to Punjab.

Table 10: Counterfactual Implications for Other Statistics relative to Baseline Model

Panel A: Change in share of farms renting land	No rentals	Efficient	No idiosyncratic	Residual
India:	-0.11	0.09	-0.04	0.13
State:				
Andhra Pradesh (AP)	-0.18	-0.05	-0.07	0.02
Assam (AS)	-0.05	0.04	-0.01	0.05
Bihar (BR)	-0.15	0.27	-0.03	0.30
Gujarat (GJ)	-0.10	0.03	-0.06	0.09
Haryana (HR)	-0.17	0.09	-0.06	0.15
Karnataka (KA)	-0.08	0.02	-0.05	0.07
Kerala (KL)	-0.09	0.18	-0.08	0.26
Maharashtra (MH)	-0.06	0.05	-0.04	0.09
Madhya Pradesh (MP)	-0.09	0.07	-0.05	0.12
Orissa (OR)	-0.09	0.08	-0.02	0.10
Punjab (PB)	-0.24	0.07	0.02	0.09
Rajasthan (RJ)	-0.07	0.07	-0.04	0.11
Tamil Nadu (TN)	-0.04	0.15	-0.03	0.18
Uttar Pradesh (UP)	-0.08	0.19	-0.04	0.23
West Bengal (WB)	-0.17	0.11	-0.04	0.15

Panel B: Change in share of land operated by 10% most productive farms	No rentals	Efficient	No idiosyncratic	Residual
India:	-0.03	0.35	0.08	0.27
State:				
Andhra Pradesh (AP)	-0.02	0.40	0.33	0.07
Assam (AS)	-0.05	0.39	0.17	0.22
Bihar (BR)	-0.03	0.24	0.04	0.20
Gujarat (GJ)	-0.04	0.47	0.20	0.27
Haryana (HR)	-0.11	0.23	0.03	0.20
Karnataka (KA)	-0.03	0.48	0.24	0.24
Kerala (KL)	0.01	0.49	0.04	0.45
Maharashtra (MH)	-0.02	0.46	0.18	0.28
Madhya Pradesh (MP)	-0.01	0.34	0.16	0.18
Orissa (OR)	-0.02	0.32	0.15	0.17
Punjab (PB)	-0.08	0.05	0.03	0.02
Rajasthan (RJ)	-0.02	0.44	0.19	0.25
Tamil Nadu (TN)	-0.04	0.46	0.10	0.36
Uttar Pradesh (UP)	-0.04	0.23	0.05	0.18
West Bengal (WB)	0.03	0.25	0.13	0.12

Notes: "No rentals" is a counterfactual where each farm operates their owned land. "Efficient" is a counterfactual efficient allocation of land. "No idiosyncratic" is a counterfactual with no idiosyncratic distortions ($\sigma^2_{\epsilon,s} = \theta_s = 0$). Residual reflects the contribution from the state-level land wedge, calculated as a residual from the difference between Efficient and No idiosyncratic counterfactuals. Change relative to baseline model.

(Residual column compared with No idiosyncratic counterfactual in panel B).

6 Conclusions

We study distortions in land rental markets and their impact on agricultural productivity across states in India. We develop a model of land rentals across heterogeneous farms and use it to estimate land market distortions for each state. We find that rental market activity has substantial positive effects on agricultural productivity. For instance, if farmers operate their owned land instead of the actual cultivated land, agricultural productivity would decline by 22 percent on average and by more than 30 percent in some states. Similarly, an efficient reallocation of land would increase agricultural TFP by 29 percent on average and by more than 50 percent in some states. Our findings suggest that land market distortions contribute substantially to agricultural productivity differences across states.

We emphasize that despite the importance of resource misallocation embedded in our results, there are substantial differences in agricultural TFP across states that remain unexplained. In our analysis, these differences are absorbed by the district-level fixed effects when measuring farm TFP. It would be interesting to investigate the role of other differences in the characteristics of agricultural production across states and the connection of these differences with land market distortions. For instance, the adoption and diffusion of modern seed varieties and modern intermediate inputs, mechanization, among other productive technologies. At the same time, it seems relevant to further study the role of state-level land quality endowments in accounting for productivity differences. We leave these important areas of research for future work.

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Appendix (for on-line publication)

A Land Reforms in India

The key elements in state land reforms were: (1) Abolition of intermediaries, (2) regulation of the size of land holdings (land ceiling legislation), and (3) tenancy reforms to improve tenure security. The abolition of intermediaries was implemented quickly and successfully. Land ceiling legislation was often ineffective at transferring holdings to landless households. Ceilings were often set too high, land that was "productively used" was exempted, and overall implementation was limited as state governments set additional costs and regulations. For example, Jin et al. (2006) describes that several states stipulated that beneficiaries of transferred land could only gain ownership rights once they had reimbursed the government for the compensation it had paid to the original landowner, and administrative expenses. In Uttar Pradesh, beneficiaries did not receive ownership rights but became government tenants. In other states, new owners did not have the right to sell their new land for more than 10 years. See also Appu et al. (1997) and Mearns (1999) for other anecdotal evidence suggesting land ceiling reform was generally implemented ineffectively. Tenancy reform encountered considerable landlord resistance. Deininger and Nagarajan (2010) notes that since the implementation of land and tenancy reforms did not start in earnest until the 1970s, it allowed landlords to prepare by often evicting tenants and resuming self-cultivation, or transforming tenants into wage workers. According to estimates by Appu et al. (1997) based on census data, about 30 million tenants—one third of the total active population in agriculture—were evicted in order to avoid having to give rights to tenants.

Table A.1 provides a summary of all land reforms passed between 1950 and 1980, as summarized by Besley and Burgess (2000), and table A.2 provides a summary of state-level restrictions on leasing land as summarized by NITI Aayog, Govt. of India (2016). The reforms show a variety of interventions across states, from providing tenure security and ownership rights to systems that limit the lease rights. The main takeaway is that tenancy reform took many different forms across states. Why did the legislation and implementation of land reforms differ so much across Indian states? In British India, land revenue systems differed markedly by state and/or district. For instance, in a landlord-based system, the landlord had effective property rights whereas in individual- or village-based system, property rights were diffused. Banerjee and Iyer (2005) argue that variation in these types of systems is mainly explained by date of British conquest. Most states that were conquered

Table A.1: Description of Land Reforms in Indian States

State	Year	Description
Andhra Pradesh (AP)	1954	Protected tenancy status, minimum lease term, right of purchase non-resumable land
	1974	Tenancy $\leq 2/3$ ceiling, confers continuous right of resumption on landowners, tenant gets right of purchase
Assam (AS)	1971	'Occupancy' tenants have tenure security and may acquire landholding, subletting disallowed
Bihar (BR)	1957	Rights of permanent tenancy in homestead lands on persons with < 1 acre of land
	1973	Prohibits subletting, prevents sub-lessees from acquiring occupancy rights
	1986	Provides underraiyats possibility to acquire occupancy rights
Gujarat (GJ)	1960	Tenants entitled to acquire ownership right after one year land expiry, dwelling sites
	1973	Regulated, limited opportunity to acquire ownership rights for tenants
Karnataka (KA)	1961	Grants tenants right to purchase, fixes tenure for 1/2 leased area
	1974	Removal of some exemptions earlier tenancy legislation
Kerala (KL)	1963	Grants tenants right to purchase
	1974	Call for employment security, fixed hours, minimum wages, etc.
	1979	Confers ownership rights on tenants with concealed tenancy
Madhya Pradesh (MP)	1959	Past leasing prohibited, entitles tenants right to acquire
Maharashtra (MH)	1950	Transfer of ownership to tenants of non-resumable lands (Marathwada region only)
	1958	Idem for all other regions
Orissa (OR)	1976	Tenure fixed for non-resumable area, subletting prohibited
Punjab (PB)	1953	Tenure security for small-scale, continuous tenants
	1955	Grants tenants right to acquire ownership of non-resumable land
	1972	Limits on tenancy regulated land
Rajasthan	1955	Confers tenure security to tenants and subtenants, ownership rights potentially transferable
Tamil Nadu (TN)	1952	Greater tenure security
	1956	Abolishment of usury and rack-renting
	1965	Prohibition of tenant eviction
	1969	Administration of tenancy records
	1971	Prohibition of tenant eviction
	1976	Acquisition rights for occupants
Uttar Pradesh (UP)	1977	Tenants given complete tenure security, leases banned
West Bengal (WB)	1950	Liberalization of sharecroppers harvest proportion
	1953	Abolition of all intermediary tenures
	1972	Full rights to tenants of homestead land
	1975	Idem
	1977	Raises presumption in favour of sharecroppers, minimum tenancy land size

Notes: Land reforms from Besley and Burgess (2000). Year refers to most recent amendment. Besley and Burgess (2000) also include amendments when measuring the number of reforms.

early had landlord-based system before conquest. As the landlord-based systems are easy to set up, but costly to change, these systems persisted into independence. After British elites experienced a shift in views on governance in the 1820s, it became easier to establish non-landlord systems in states that came under British control at a later stage. After independence, there was more class-based resentment in states with landlord-based systems, which fuelled demands for land reforms (e.g., Gough, 1974).

Table A.2: Description of Tenancy Reforms in India

State	Law Governing Leasing	Nature of Legal Restrictions on Land Leasing
Andhra Pradesh	Andhra Pradesh (Andhra Area) Tenancy Act, 1956, as amended in 1974	There is no explicit ban on leasing. But terms and condition of lease are restrictive. Any lease after 1974 has to be in writing and registered, for a minimum period of six years. Also on resumption of land by the landowner, the tenant has to be left with not less than one half of the land held by him under lease prior to such resumption.
Telangana	The Andhra Pradesh (Telengana Area) Tenancy & Agriculture Act, 1950, as amended in 1951, 1954, 1956, 1961, 1969 and 1979	Leasing is prohibited except by certain categories of land owners, such as (a)land owners who hold land equal to or less than 3 times the family holding* (section-7) and (b) disabled persons (a minor, a female, persons with physical and mental infirmity, persons in defence services with permission of district collector. A copy of every lease shall be filed before the tehsildar.
Assam	Assam (Temporarily settled Areas) Tenancy Act, 1971, applicable to the entire state	(a) No explicit ban on land leasing; (b) sub-letting is prohibited; (c) occupancy tenants who have held land as tenant for at least 3 years continuously enjoy security of tenure and can acquire ownership right on payment of compensation at the rate of 50 times the rate of annual revenue, payable for such lands; (d) Non-occupancy tenant can acquire the right of occupancy, if he has held land continuously for 3 years.
Bihar	Bihar Land Reforms Act, 1961	Leasing is prohibited except by disabled ryots i.e. minor, widow, or unmarried, divorced or separated woman, or person with physical or mental disability or a person in the armed forces or a public servant in receipt of salary not exceeding Rs. 250 per month (Section-19)
Jharkhand	Chhotanagpur Tenancy Act, 1908 and Santhal Pargana Tenancy Act, 1945	Leasing is prohibited, except with permission of a competent authority, i.e the Deputy Commissioner. This is required not only for Adivasis, but also for Scheduled Caste or backward caste raiyats to lease out land. Besides, the land cannot be transferred even to an Adivasi who does not reside within the jurisdiction of the same police station to which the landowner belongs. (Section – 46(1) of CNTA)
Gujarat	Bombay Tenancy And Agril, Land Act 1948, as amended by Act No. 5 of 1973 (erstwhile Bombay areas)	No explicit ban on land leasing, but land owner has a risk of losing land right, due to creation of tenancy. A tenant acquires the right to purchase the land leased in within one year of lease period. Legal leases are possible only when the tenant is not in a position to exercise his/her right to purchase due to financial difficulties or otherwise.

Table A.2: Description of Tenancy Reforms in India

State	Law Governing Leasing	Nature of Legal Restrictions on Land Leasing
Gujarat	Saurashtra Land Reforms Act, 1951 and Prohibition of Leases Act, 1953	Renewal of lease or grant of a fresh lease after 1.9.1954 is prohibited except by persons under disability such as a widow, a minor, a member of the armed forces or persons suffering from physical or mental disability, government, local authority, industrial and commercial undertakings.
Gujarat	Bombay Tenancy and Agricultural land (Vidharbha and Kutch Area) Act, 1958, as amended by Govt. of Gujarat in 1961, 1964, 1965, 1968 and 1973)	No explicit ban on land leasing. But the Act provides for voluntary purchase of ownership right.
Himachal Pradesh	The H.P. Tenancy and Land Reforms Act, 1972, as amended in 1976 and 1987	Leasing out is banned except by disabled persons such as members of armed forces unmarried/ divorced/separated women, a widow, a minor, persons under physical or mental disability or a student of a recognized institution
Jammu & Kashmir	The Jammu & Kashmir Agrarian Reforms Act, 1976	Creation of tenancy is banned without any exception
Karnataka	The Mysore Land Reforms Act, 1961 as amended w.e.f. 1 March, 1974	Leasing out is banned excepting by a soldier or a seaman
Kerala	Kerala Land Reforms Act, 1963, as amended in 1969, 1971, 1972 and 1973	Leasing out is banned without any exception
Madhya Pradesh & Chhattisgarh	MP Land Revenue code, 1959, as amended uptodate	Leasing out is prohibited except by a disabled person (a widow, unmarried woman, married but separated woman, a minor, a person in imprisonment, a person serving in armed forces, a public charitable/religious institution or a local authority or a cooperative society
Maharashtra	Bombay Tenancy and Agricultural land Act,1948, as amended in 1956 (for old Bombay area) and The Hyderabad Tenancy and Agricultural Lands Act, 1950, as amended in 1954 for Marathwada (Hyderabad area)	No explicit legal ban on leasing. But land owner has a risk, as tenant has a right to purchase the land leased by him within one year of creation of tenancy. Any tenancy created after the tillers (i.e. 1st April, 1957) day, (excepting by the serving member of armed forces) is void, as the tenants shall acquire the right to purchase. Tenant cultivating personally on 1st April, 1957, i.e. the tillers day, shall be deemed to have purchased from the land lord the ownership right upto the ceiling area.

Table A.2: Description of Tenancy Reforms in India

State	Law Governing Leasing	Nature of Legal Restrictions on Land Leasing
Odisha	Orissa Land Reforms Act, 1965, as amended in 1973 and 1976	Leasing out agricultural land is banned except by a person under disability or under a privileged raiyat w.e.f. 1.10.1965. A person under disability includes: (i) a widow or unmarried or separated women (ii) a minor, (iii) a person incapable of cultivating land due to physical or mental disability (iv) a serving member of armed forces (v) a raiyat whose land holding does not exceed 3 standard acres. A privileged raiyat means Lord Jagannath, any trust or institution declared as a privileged raiyat or any other religious or charitable trust of a public nature.
Manipur	The Manipur Land Revenue and Land Reforms Act, 1960 as amended in 1975 (applicable to plain areas only)	Leasing in future is banned except by a person under disability.
Punjab	Punjab Tenancy Act, 1887, The PEPSU Tenancy and Agricultural Lands Act, 1955, as amended in 1957, 1959, 1962, 1968 and 1969; Punjab Security of Land Tenancy Act, 1953 as amended in 1955, 1957, 1959, 1962, 1968 and 1969 and Punjab Land Reforms Act, 1972	No explicit ban on leasing. But section 16 of the LR Act, 1972 provides that the tenant of a big landowner is entitled to purchase his tenanted land, if he has been in continuous possession of the land for a minimum period of six years, if the land is not included within the reserved or ceiling area of the land owner or when the land owner is a disabled person, (widow or unmarried woman or a person suffering from physical or mental disability and also the tenant must have land below ceiling. Also a landowner within ceiling can evict a tenant, subject to the tenant being left with not less than 5 standard acres.
Haryana	Punjab Security of Land Tenures Act, 1953 for the erstwhile Punjab area and PEPSU Tenancy and Agricultural Land Act, 1955 for PEPSU area, as amended uptodate.	No explicit ban on land leasing. But there are other restrictive clauses, as in Punjab. However, the Haryana law not provide for any automatic right of purchase on tenanted land falling within the ceiling surplus areas of land owner, as in Punjab. Such land vests in the Govt, although tenants are given preference in the allotment of such lands. Also a tenant can lease in land for a minimum period of 3 years, but less than six years.
Rajasthan	Rajasthan Tenancy Act, 1955	There is no explicit ban on land leasing. But terms and conditions of lease are restrictive. Also a tenant is entitled to a written lease, which may be attested if not registered.
Tamil Nadu	Madras cultivating tenants protection Act, 1955 as amended in 1965 and Madras cultivating Tenants (payment of Fair rent) Act, 1956	No explicit ban on leasing. But landlord can resume land for personal cultivation, not exceeding one-half of the land leased out to the tenant excepting when he is a member of armed forces. If the landlord owns above 13.5 acres of wet land or pays sales tax or professional tax or income tax, he cannot even resume land from tenant. Also any tenant or agricultural labourer occupying any Kudiyirupees (a dwelling house or hut) cannot be evicted.

Table A.2: Description of Tenancy Reforms in India

State	Law Governing Leasing	Nature of Legal Restrictions on Land Leasing
Tripura	The Tripura Land Revenue and Land Reforms Act, 1960	A raiyat or jotedar can lease out, but the lessee will hold it in perpetuity which cannot be terminated except by a person under disability i.e. widow, a minor, an unmarried woman or if married, divorced or judicially separated, a member of the armed forces, a person under physical or mental disability. A lessee/under raiyat cannot be evicted from his land except by an order of competent authority on specific grounds.
Uttar Pradesh & Uttarakhand	The Uttar Pradesh Zamindari Abolition Land Reforms Act, 1950	Leasing in future is banned except by a disabled person and to agriculture related educational institution. A disabled person is defined as an unmarried/divorced/ separated woman, a widow or a woman whose husband is incapable of cultivating due to physical or mental infirmity or a minor whose father suffers from infirmity or person who is a lunatic or an idiot or blind or a student of a recognized educational institution whose age does not exceed 25 years and whose father suffers from infirmity or a serving member of the armed forces or a person under detention or imprisonment.
West Bengal	The West Bengal Land Reforms Act, 1955 as amended in 1970, 1971 and 1981	Lease on share cropping only is allowed. No fixed rent or fixed produce tenancy is allowed, not even by a person under disability of any kind

Source: NITI Aayog, Govt. of India (2016).

B Additional Tables and Figures

Table B.3: Determinants of Rental Market Activity—Including Sharecropping

	Dependent variable is whether a farm rents in land or not				
	(1)	(2)	(3)	(4)	(5)
	Probit	Probit	Probit	Probit	Probit
TFP (log)	0.143***	0.154***	0.344***	0.369***	0.369***
	(0.0329)	(0.0349)	(0.0341)	(0.0366)	(0.0393)
Own land (log)			-0.367***	-0.354***	-0.354***
			(0.0536)	(0.0508)	(0.0501)
State FE	N	Y	Y	Y	Y
Demographic controls	N	N	N	Y	Y
Land quality controls	N	N	N	N	Y
Observations	8359	8359	8359	8359	8359
R^2	0.01	0.08	0.125	0.14	0.14

Notes: In contrast to the main text, we classify sharecropping farmers as renters. Standard errors in parentheses, clustered by state. We standardize log TFP and log owned land within states. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$

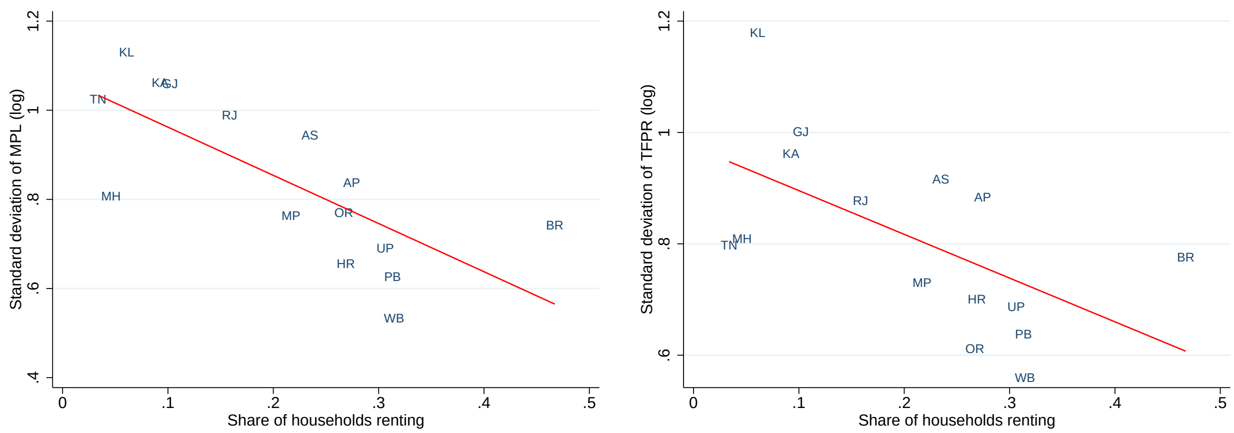
Table B.4: Land Rental Markets and Misallocation—Including Sharecropping

Panel A: Dependent variable is absolute deviation of (log) marginal product of land from state mean					
	(1)	(2)	(3)	(4)	(5)
	OLS	OLS	OLS	OLS	OLS
Share hh renting	-0.934**	-0.934**	-0.938**	-0.790**	-1.018***
	(0.329)	(0.329)	(0.325)	(0.304)	(0.192)
TFP (log)		-0.0155*	-0.0148	-0.0107	-0.0134
		(0.00799)	(0.00850)	(0.00749)	(0.00821)
Demographic controls	N	N	Y	Y	Y
Land quality controls	N	N	N	Y	Y
State-level controls	N	N	N	N	Y
Observations	8617	8617	8617	8617	8617
R^2	0.028	0.029	0.029	0.038	0.051

Panel B: Dependent variable is absolute deviation of (log) TFPR from state mean					
	(1)	(2)	(3)	(4)	(5)
	OLS	OLS	OLS	OLS	OLS
Share hh renting	-0.687**	-0.687**	-0.689**	-0.570**	-0.728***
	(0.249)	(0.249)	(0.245)	(0.245)	(0.228)
TFP (log)		-0.00276	-0.00460	-0.00233	-0.00168
		(0.00654)	(0.00789)	(0.00859)	(0.00832)
Demographic controls	N	N	Y	Y	Y
Land quality controls	N	N	N	Y	Y
State-level controls	N	N	N	N	Y
Observations	8638	8638	8638	8638	8638
R^2	0.022	0.022	0.024	0.029	0.041

Notes: In contrast to the main text, we classify sharecropping farmers as renters. Standard errors in parentheses, clustered by state. We standardize log TFP and log owned land within states. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$

Figure B.1: Rental Market Activity and Misallocation - Incl. Sharecropping



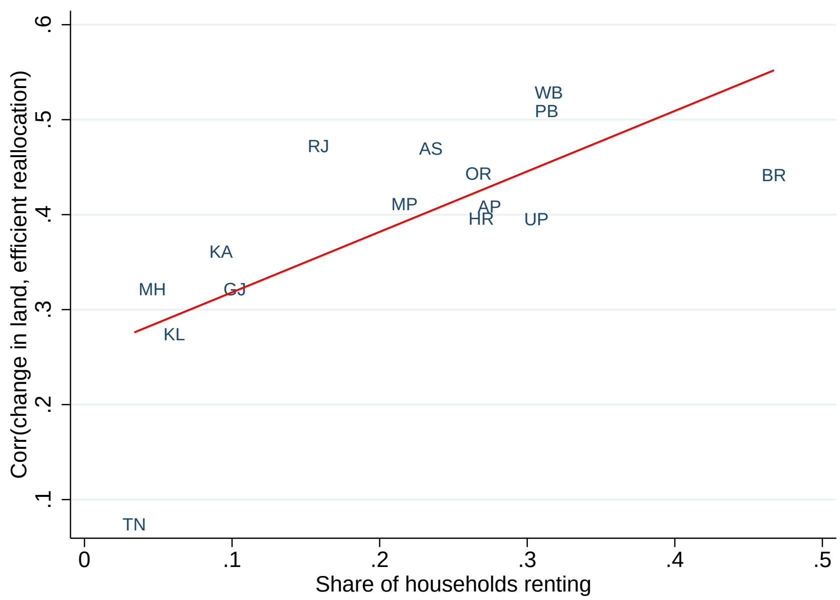
Notes: In contrast to the main text, we classify sharecropping farmers as renters. Panel (a) reports the standard deviation of (log) farm-level MPL and panel (b) the standard deviation of (log) TFPR both with respect to the share of households renting in each state.

Table B.5: Land Reallocation and Rental Markets—Including Sharecropping

Dependent variable is change in (log) cultivated land between waves I and II	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS
Reallocation potential wave I	0.273***	0.177***	0.142***	0.145***	0.126***
	(0.0274)	(0.0329)	(0.0185)	(0.0189)	(0.0201)
Reallocation potential wave I		0.599***	0.750***	0.743***	0.776***
		(0.160)	(0.108)	(0.107)	(0.107)
State FE	N	N	Y	Y	Y
Demographic controls	N	N	N	Y	Y
Land quality controls	N	N	N	N	Y
Observations	8638	8638	8638	8638	8638
R^2	0.150	0.160	0.222	0.225	0.233

Notes: In contrast to the main text, we classify sharecropping farmers as renters. Standard errors in parentheses, clustered by state. We standardize log TFP and log owned land within states. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$

Figure B.2: Land Reallocation and Rental Market Activity—Including Sharecropping



Notes: In contrast to the main text, we classify sharecropping farmers as renters. The correlation between farm-level change in cultivated land and reallocation potential in wave I and the share of households participating in the rental market across states. Data from IHDS-I and IHDS-II.

C Solving for the Decentralized Equilibrium

We use the following algorithm to solve for the decentralized equilibrium in an economy with F_s farmers which are endowed with land $\bar{l}_{is}$ and TFP z_{is}.

Given each state distortions θ_s, τ_s, and $\sigma_{\epsilon,s}$, perform the following steps:

1. For each farmer, draw $\epsilon_{is} \sim N(0, \sigma^2_{\epsilon,s})$.
2. Compute $MPL_{l_{it}=\bar{l}_{is}} = \gamma z_{is}(\bar{l}_{is})^{\gamma-1}$.
3. Guess land price q_s (the initial guess could be the land price associated with the efficient allocation of resources) and compute:
   - $q^{in}_{is} = \ln q_s + \theta \ln z_{is} + \epsilon_{is}$,
   - $q^{out}_{is} = \ln q_s + \theta \ln z_{is} - \ln(1 + \tau_s) + \epsilon_{is}$.
4. Partition farmers into three sets and compute demand for land l^D_{is} for each farmer:
   - $l^D_{is} = (\frac{\gamma z_{is}}{q^{in}_{is}})^{\frac{1}{1-\gamma}}$ if $\ln MPL_{l_{it}=\bar{l}_{is}} > q^{in}_{is}$,
   - $l^D_{is} = (\frac{\gamma z_{is}}{q^{out}_{is}})^{\frac{1}{1-\gamma}}$ if $\ln MPL_{l_{it}=\bar{l}_{is}} < q^{out}_{is}$,
   - $l^D_{is} = \bar{l}_{is}$ if $q^{in}_{is} \geq \ln MPL_{l_{it}=\bar{l}_{is}} \geq q^{out}_{is}$.
5. Compute total demand L^D_s and total supply L^S_s of land:
   - $L^D_s = \sum_{i=1}^{F_s} l^D_{is}$,
   - $L^S_s = \sum_{i=1}^{F_s} \bar{l}_{is}$.
6. Check $f = L^D_s - L^S_s$. If not converged, i.e., f not close to 0, update guess of q_s and iterate on (3)-(6) until convergence.

D Estimation of Land Distortions

This section describes in detail the procedure for estimating land market distortions τ_s, θ_s, and $\sigma_{\epsilon,s}$.

Variation in the data. We use three sources of variation in the data to identify the three parameters determining land distortions:

- If $\tau_s = 0$, most farmers participate in the rental market. The share of farmers renting in thus gives us variation to identify τ_s.
- If $\tau_s = 0$ and $\theta_s = 0$, the covariance between $\ln MPL_{is}$ and $\ln z_{is}$ equals zero. This covariance thus gives us variation to identify θ_s, conditional on τ_s.
- If $\tau_s = 0$, $\theta_s = 0$ and $\sigma^2_{\epsilon,s} = 0$, the variance of $\ln MPL_{is}$ equals zero. This variance thus gives us variation to identify $\sigma^2_{\epsilon,s}$, conditional on τ_s and θ_s.

Formally, we use three population moments (indexed by M^x):

(M^1) $cov(\ln MPL_{is}, \ln z_{is}) = cov(\mathbb{1}\{l^{out}_{is} > 0\}(\ln q_s + \theta_s \ln z_{is} - \ln(1+\tau_s) + \epsilon_{is}) + \mathbb{1}\{l^{in}_{is} > 0\}(\ln q_s + \theta_s \ln z_{is} + \epsilon_{is}) + \mathbb{1}\{l^{out}_{is} = l^{in}_{is} = 0\}(\ln z_{is}(\bar{l}_{is})^{\gamma}), \ln z_{is})$,

(M^2) $var(\ln MPL_{is}) = var(\mathbb{1}\{l^{out}_{is} > 0\}(\ln q_s + \theta_s \ln z_{is} - \ln(1+\tau_s) + \epsilon_{is}) + \mathbb{1}\{l^{in}_{is} > 0\}(\ln q_s + \theta_s \ln z_{is} + \epsilon_{is}) + \mathbb{1}\{l^{out}_{is} = l^{in}_{is} = 0\}(\ln z_{is}(\bar{l}_{is})^{\gamma}))$,

(M^3) $1 - \mathbb{E}(l^{in}_{is} > 0) = \Phi(\frac{1}{\sigma_{\epsilon,s}}(\ln MPL_{is} - \theta_s \ln z_{is} + (\ln(1+\tau_s) - \ln q_s))$.

Note that if $\tau_s = 0$, the first two moments simplify to the closed form solutions $cov(\ln MPL_{is}, \ln z_{is}) = \theta_s var(\ln z_{is})$ and $var(\ln MPL_{is}) = \theta_s^2 var(\ln z_{is}) + \sigma^2_{\epsilon,s}$. Note that conditional on other parameters, θ_s governs M^1, $\sigma^2_{\epsilon,s}$ governs M^2, and τ_s governs M^3.

Algorithm. We follow these steps to find parameter values for distortions:

1. Guess initial parameters $(\tilde{\theta}_s)_1$, $(\tilde{\sigma}^2_{\epsilon,s})_1$, $(\tilde{\tau}_s)_1$.
2. For each of X different sets of draws $\{\epsilon^x_{is}\}_{i=1}^{F_s}$, solve the decentralized equilibrium using the algorithm in Appendix C.
3. Compute implied moments by averaging over X equilibria:

   ($\tilde{M}^1$) $\tilde{cov}(\ln MPL_{is}, \ln z_{is})$,

   ($\tilde{M}^2$) $\tilde{var}(\ln MPL_{is})$,

   ($\tilde{M}^3_1$) $1 - \sum_{i=1}^{F_s} \mathbb{1}(l^{in}_{is} > 0)$.

4. Compute distance D_t between actual moments (M^x) and implied moments ($\tilde{M}_t^x$).

5. If not converged, construct new implied moments using adjusted parameter guesses. Separately identify q_s and τ_s using:

$$\mathbb{E}(\ln MPL_{is}) = \ln q_s + \theta_s \mathbb{E}(\ln z_{is}) - (\ln(1+\tau_s))\mathbb{E}(l_{is}^{out} > 0).$$

6. Iterate (2)-(4) until distance is less than tolerance.