Supplemental Appendix: "Misallocation in Indian Agriculture"†

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A Land Reforms in India

The key elements of land reforms were: (i) abolition of intermediaries, (ii) regulation of the size of land holdings (land ceiling legislation), and (iii) tenancy reforms to improve tenure security. Governments implemented the abolition of intermediaries quickly and successfully. Land ceiling legislation was often ineffective at transferring holdings to landless households. Authorities often set ceilings too high, as they exempted land that was "productively used". Overall implementation was limited as state governments set additional costs and regulations. For example, Jin et al. (2006) describe how several states stipulated that beneficiaries of transferred land could only gain ownership rights once they had reimbursed the government for administrative expenses and the compensation it had paid to the original landowner. 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.[1]

Tenancy reform encountered considerable landlord resistance. Deininger et al. (2009) note that the implementation of land and tenancy reforms did not start in earnest until the 1970s. This allowed landlords to prepare by often evicting tenants and resuming self-cultivation, or by transforming tenants into wage workers. According to estimates by Appu et al. (1997)

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[1] See also Appu et al. (1997) and Mearns (1999) for other anecdotal evidence suggesting that authorities implemented land ceiling reforms ineffectively.

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: 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.

Table A.1 provides a summary of all land reforms passed between 1950 and 1980 from Besley and Burgess (2000). Table A.2 summarizes each state's restrictions on leasing land from India NITI Aayog (2016). The reforms show a variety of interventions across states, from providing tenure security and ownership rights to systems that limit 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 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 early had landlord-based system before conquest. As the landlord-based systems were 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. Independence fueled class-based resentment in states with landlord-based systems, which led to 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 the terms and conditions of leasing 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 for certain categories of land owners, such as (a) landowners who own land equal to or less than three 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.	No explicit ban on land leasing. Sub-letting is prohibited. Occupancy tenants who have held land as tenant for at least three 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. Non-occupancy tenant can acquire the right of occupancy if he has held land continuously for three years.

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Table A.2 — *Continued from previous page*

State	Law Governing Leasing	Nature of Legal Restrictions on Land Leasing
Bihar	Bihar Land Reforms Act, 1961.	Leasing is prohibited except by disabled ryots, i.e. a minor, a widow, or an unmarried, divorced or separated woman, or a 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 from a competent authority (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 the landowner risks losing the land when the tenancy is created. A tenant acquires the right to purchase the land leased within one year of lease period. Legal leases are possible only when the tenant is not in the position to exercise his or her right to purchase, due to financial difficulties or otherwise.
Gujarat	Saurashtra Land Reforms Act, 1951 and Prohibition of Leases Act, 1953.	Renewal of lease or 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, or 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 when done by disabled persons such as members of armed forces, unmarried, divorced or 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 except when done 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.

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Table A.2 — *Continued from previous page*

State	Law Governing Leasing	Nature of Legal Restrictions on Land Leasing
Madhya Pradesh & Chhattisgarh	MP Land Revenue code, 1959, as amended up to date.	Leasing out is prohibited except when done 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 or religious institution, or a local authority, or a co-operative society).
Maharashtra	Bombay Tenancy and Agricultural land Act,1948, as amended in 1956 (for the 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 the tenant has the right to purchase the land leased by him within one year of the creation of the tenancy. Any tenancy created after the tillers (i.e. 1st April, 1957) day, (except by the serving member of armed forces) is void, as the tenants shall acquire the right to purchase. Tenants cultivating personally on 1st April, 1957, i.e. the tillers day, shall be deemed to have purchased the ownership right from the landlord up to the ceiling area.
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 is banned except by a person with a 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 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 landowner, or when the landowner is a disabled person (widow or unmarried woman, or a person suffering from physical or mental disability). The land of the tenant must be below the ceiling. the tenant must have land below ceiling. A landowner with land below the ceiling can evict a tenant, subject to the tenant being left with not less than five standard acres.

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Table A.2 — *Continued from previous page*

State	Law Governing Leasing	Nature of Legal Restrictions on Land Leasing
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 up to date.	No explicit ban on land leasing. But there are other restrictive clauses, as in Punjab. However, the Haryana law does not provide the right to purchase rented land land falling within the ceiling surplus areas of land owner, as in Punjab. Such land vests in the government, although tenants are given preference in the allotment of such lands. A tenant can lease in land for a minimum period of three years, and a maximum of six years.
Rajasthan	Rajasthan Tenancy Act, 1955.	There is no explicit ban on land leasing. But the terms and conditions of lease are restrictive. 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.	There is no explicit ban on leasing. But the landlord can use the land for personal cultivation, not exceeding one half of the land leased out to the tenant except when he is a member of armed forces. If the landlord owns above 13.5 acres of wet land, or pays sales, professional, or income tax, he cannot even resume land from the tenant. A tenant or agricultural laborer occupying any Kudiyirupees (a dwelling house or hut) cannot be evicted.
Tripura	The Tripura Land Revenue and Land Reforms Act, 1960.	A raiyat or jotedar can lease out, but the tenant can hold the land in perpetuity. The lease cannot be terminated except by a person with a disability, i.e. a widow, a minor, an unmarried woman, or a divorced or judicially separated woman, or a member of the armed forces, or a person under physical or mental disability. A tenant under raiyat cannot be evicted from his land except by an order of a competent authority on specific grounds.
Uttar Pradesh & Uttarakhand	The Uttar Pradesh Zamindari Abolition Land Reforms Act, 1950.	Leasing is banned except when done by a disabled person and to agriculture-related educational institutions. A disabled person is defined as an unmarried, divorced, or 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 a 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.	Only sharecropping is allowed. No fixed rent or fixed produce tenancy is allowed, not even by a person with a disability of any kind.

Notes: Source India NITI Aayog (2016).

B Data

We describe more details of data, constructed variables, and sample selection. We also provide details of expenditure measures used for the production function parameter estimates.

B.1 Variables and Sample Selection

Real gross output. A natural measure of real output at the farm level is crop output aggregated using constant crop prices across farms and time. However, only wave I of IHDS reports crop-level output. We first calculate nominal farm revenue by aggregating up crop level revenue using farm-level prices reported in wave I. While wave II of IHDS does not report the crop-level output information for farms, it however provides the total nominal revenue calculated by using the crop quantities and price information that is not publicly available in the IHDS database. Because we lack data on price deflators for agriculture by state, we use the food consumption price index (CPI) for agricultural workers in each state from the Indian Ministry of Labour and Employment (India Labour Bureau, 2015). We express constant prices over time relative to wave I using the CPI for India (Organization for Economic Co-operation and Development, 2022) and across states relative to Punjab. We corroborate that our revenue measure of output correlates strongly with the real measure of output from wave I using common prices for crops, with a mean correlation across states of 78 percent.

Land. Wave I reports total land owned, own land cultivated, land rented-in, and land rented-out by the farmer in the last 12 months. Wave II reports total land owned, land rented-in, and land rented-out by farmer in each of the three main cropping seasons in India - kharif, rabi, and summer. We measure total land cultivated as the sum of own land cultivated and land rented-in in wave I. In wave II, we calculate total land cultivated (own land + rented-in − rented-out) by season and then take the maximum value of the three. Similarly, total land rented-in and rented-out are taken as the maximum over all three seasons reported.

Labor. Both waves report details on hired and household labor. Hired labor is reported in total mandays hired in the last 12 months. Household labor is reported in terms of the average number of hours and the average number of days a year each member of the household worked on the farm. We calculate total number of hours of labor provided by the household and use a value of 8 hours per manday to convert to total mandays. We do not include the labor provided by the farm head, household head, or their spouse in total labor as we believe they capture managerial inputs for the farm and should be captured in farm productivity. The IHDS village data file provides average agriculture wages paid to men, women, and children separately. We adjust household labor by deflating the hours worked by women and children using the relative median wages paid to them from the village data file.

Capital. The stock of capital is calculated as the value of electric pumps, diesel pumps, bullock carts, tractors, threshers, and draft animals owned by the farm. We impute the value of machinery using 1997-98 prices reported in table 24 of Singh (2006). Electric and diesel pumps are priced at Rs. 18,000, bullock carts at Rs. 10,000, tractors at Rs. 250,000, and threshers at Rs. 25,000. For draft animals, we first take the average value of the minimum and maximum reported price for draft animals in the village database of the respective wave of IHDS, and then use the median of this value. A measure of capital stock owned is then constructed as the total value of all machinery and draft animals owned by the farm.

IHDS also reports expenditure on renting capital as well as income made from renting out capital from the farm. We convert these rental values to capital stock values by deflating with a measure of real interest rate in each wave. We use the median nominal interest rate paid by households on loans from banks (reported in the household data file of the IHDS) and adjust it using the inflation rate for the corresponding year to convert to real terms. Total capital stock employed on the farm is calculated as capital owned plus capital rented in minus any capital rented out. To this value we finally add a minimum amount of capital to every household equal to 10 percent of the median capital-to-land ratio multiplied by operated land to account for basic tools used on the farm not usually reported in the data.

Materials. We use the sum of expenditure on seeds, fertilizers, pesticides, and other miscellaneous expenses and deflate it using the price of kerosene that the household pays as the amount of materials used on the farm. While the level of kerosene prices 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 believe kerosene prices are a good proxy since they reflect the same relative trade costs that drive relative intermediate input prices. For those households that report zero spending on material inputs, we impute material expenditure as the minimum value of material-to-land ratio multiplied by operated land.

Final sample. We start by dropping all households who report no cultivated land or zero agriculture output in each wave. Of the 14,738 households participating in agriculture in wave-I, we match 10,253 to wave-II to create a balanced panel. The rest of the households are dropped either because they leave farming, split up households, or are lost to re-contact. After restricting our analysis to states with an estimated population of more than 20 million, we are left with a sample of 8,147 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.

Once we estimate the permanent component of TFP, we trim our sample by dropping the top and bottom 1% of the TFP distribution by state. Finally, we exclude households that experience large changes in land-to-output ratios between the two waves. This leaves us with 7,846 households across 15 states. We use sample weights provided in the dataset to expand the dataset for all quantitative exercises.

B.2 Production Function and Productivity

Production function parameters. In order to measure farm productivity, recall that we assume a common production function that only differs across farmers in terms of their total factor productivity given by equation (**??**). We use aggregate expenditure shares of revenue of factor inputs for all farms in the data to calibrate each input elasticity following the literature that uses factor cost shares to estimate production functions (Syverson, 2004; Raval, 2023). This approach is common in the macroeconomics literature Valentinyi and Herrendorf (2008) and in particular a recent literature on agriculture (Adamopoulos and Restuccia, 2014; Chen et al., 2023). Under the assumptions that farms are price takers and minimize costs, and that static first order condition for each input holds on average in the market, we can map each factor's expenditure relative to total farm revenue to its output elasticity in the production function.

To measure factor shares, we convert input quantities to input expenditures using common prices for all farms in India. For land, we use the rental price paid by farms renting-in land. These rents can be paid either in cash, as a share of crop, or both. We back out a measure of the rental price of land by using the median price paid by farmers per unit of land rented-in by cash only in each wave respectively. Land expenditure is calculated as the product of total operated land and the median rental price.

For labor, we use the median wage rate paid for hired labor (using only those households that do not provide meals to hired labor) to obtain a measure of expenditure on hired labor. Expenditure spent on household labor is constructed as the product of the adjusted household labor with the median agriculture wage paid to men from the village data file. Total labor expenditure is the sum of expenditure on hired and household labor.

We convert the constructed capital stock value into expenditure terms by multiplying it with the rental rate of capital for each wave (described above in the variables description). Materials are converted into expenditure terms using a common price set as the median price of kerosene in the dataset.

Table B.3 reports the factor shares for capital, land, labor, and materials using data from IHDS-I and the implied production function parameter values. The resulting parameter estimates are broadly consistent with estimates from other studies (Adamopoulos et al., 2022; Aragón et al., 2022; Chen et al., 2022).

Table B.3: Factor Input Shares and Production Function Parameters

Input factor	Output elasticity	Data	Parameter	Value
Capital	$\alpha(1-\theta)\gamma$	0.11	α	0.20
Land	$\beta(1-\theta)\gamma$	0.25	β	0.43
Labor	$(1-\alpha-\beta)(1-\theta)\gamma$	0.19	θ	0.28
Materials	$\theta\gamma$	0.20	γ	0.75

Notes: Data from IHDS wave I 2004-05 (Desai et al., 2005). Factor shares are calculated as the ratio of input expenditure across farms in India to the value of total farm output.

Crop-level production. Note that while our data reports crop-level output for wave I, we do not have information on inputs used by crop within the farm required to estimate crop-level productivity. Moreover, crop-level information is not reported in wave II which would prevent us from estimating the permanent component of farm productivity. However, we examine potential differences in factor shares across crops. We classify farm households that generate more than 50 percent of their estimated revenue from a single crop and restrict to crops that are produced by at least 100 farm households in the wave I sample. Estimating factor shares as described previously, we find that factor shares are roughly similar across crops and in line to the baseline values used in our calibration.

To allay concerns that crop differences in factor shares can substantially affect our farm productivity estimates, we back out production function residuals $\ln a_{ist}$ using crop-specific input shares and compare them to our baseline production function residuals. We find that the two measures of farm productivity (in logs) are strongly correlated across farms within states with West Bengal having the smallest correlation coefficient of 0.86 and Assam having the highest correlation at 0.97, and the average correlation coefficient across states being 0.93.

Land as composite input. Our analysis focuses on a production function with land as a composite input. This implies that we abstract from any variation in input ratios across farms and, as a result, is conservative in the quantification of reallocation gains. We write the production function defined in equation (**??**) in the main text in terms of input ratios and land (with state and time subscripts dropped for ease of exposition):

$$y_i = z_i \underbrace{\left[\left((k_i/\ell_i)^{\alpha} (n_i/\ell_i)^{1-\alpha-\beta} \right)^{1-\theta} (m_i/\ell_i)^{\theta} \right]^{\gamma}}_{\text{Input ratios: } T_i} \ell_i^{\gamma} \tag{B.1}$$

To the extent that the variation in input ratios may be due to technology differences across farmers (the type of technology they use or the type of crops they grow), we abstract from this source of variation in our analysis. As discussed in the institutional context, legal rights 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. Nevertheless, we emphasize that in measuring farm-level total factor productivity in the data, we do control for all factor inputs in addition to land.

We also note that in our data, the variation in input ratios across farms accounts for less than 14% of the variation in output. Taking the logarithm of equation (B.1), we have

$$\ln(y_i) = \ln(z_i) + \ln(T_i) + \gamma \ln(\ell_i), \tag{B.2}$$

where T_i represents the component of the production function that captures variation in input ratios across farms.

Table B.4: Variance Decomposition of Production Function

	(1) $\ln(z_i)$	(2) $\ln(T_i)$	(3) $\gamma \ln(\ell_i)$
$\ln(y_i)$	0.366***	0.137***	0.497***
	(0.005)	(0.005)	(0.005)
Observations	7,846	7,846	7,846
R-squared	0.453	0.094	0.527

Notes: Standard errors in parentheses. Each column regresses a component of the production function in equation (B.2) on the log of output, including a constant. The estimate represents the fraction of the variance in the log of output explained by the variance in the respective component of the production function. The coefficients in each column sum to 1. *p<0.10, **p<0.05, ***p<0.01.

Table B.4 reports the regression coefficients from regressing each of the components on the right hand side of equation (B.2) on the log of output separately. Each of the coefficients represent the fraction of the variance in the log of output explained by the variation in the corresponding factor, which all sum to one. We find that while the composite land input accounts for around 49.7% of the variation in output, the component made up of the other input ratios, T_i, captures only 13.7%.

C Efficient Allocations and Gains.

Since our analysis focuses on land as a composite input, we measure farm output in the data based on our estimates of farm productivity z_{is} and operated land ℓ_{is} for all farms and states in our data using the production function $y_{is} = z_{is}\ell_{is}^{\gamma}$. Then aggregate agricultural output is the sum of farm output in each state.

A useful benchmark for comparing allocations and aggregate outcomes is the efficient allocation, i.e., the allocation that maximizes aggregate output in a state given aggregate inputs. We characterize each state efficient allocation by solving the farm-level allocation of land that maximizes aggregate output subject to the state's endowment of land L_s:

$$\max_{\{\ell_{is}\geq 0\}_{i=1}^{F_s}} \sum_{i=1}^{F_s} z_{is}\ell_{is}^{\gamma}, \qquad \text{subject to} \qquad \sum_{i=1}^{F_s} \ell_{is} = L_s.$$

The efficient allocation with superscript e involves allocating factors across the given set of F_s farmers in state s according to their relative productivity given by:

$$\ell_{is}^{e} = \frac{z_{is}^{\frac{1}{1-\gamma}}}{\sum_{i=1}^{F_s} z_{is}^{\frac{1}{1-\gamma}}} L_s.$$

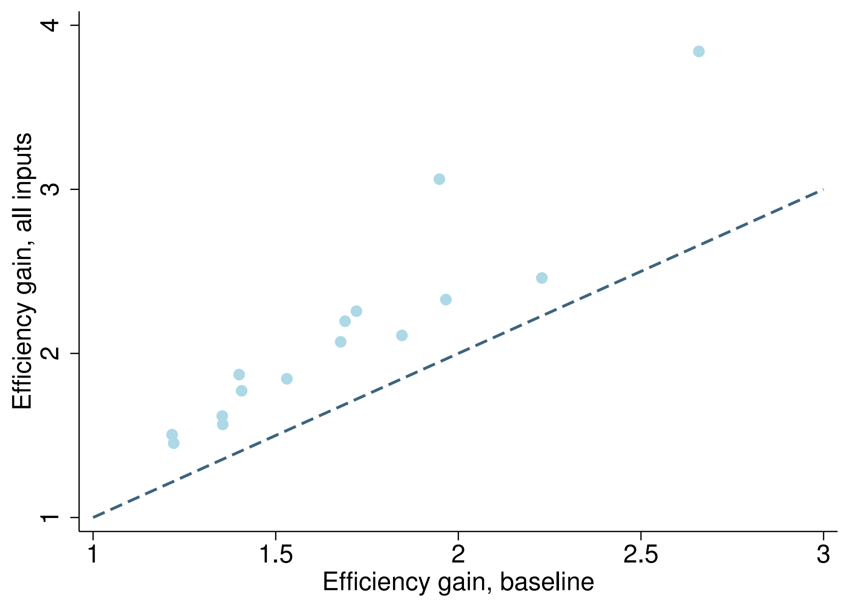
It is straightforward to show that aggregate output in the efficient allocation, Y_s^e, is a Cobb-Douglas aggregate of total inputs (land and total number of farms), and agricultural TFP A_s^e, see Adamopoulos et al. (2022) for a derivation and extension with more inputs:

$$Y_s^e = A_s^e F_s^{1-\gamma} L_s^{\gamma}, \qquad \text{where} \qquad A_s^e = \left[\frac{1}{F_s}\sum_{i=1}^{F_s} z_{is}^{\frac{1}{1-\gamma}}\right]^{1-\gamma}.$$

We define efficiency gain as the ratio of aggregate efficient output to aggregate actual output in the data for each state, Y_s^e/Y_s^a (Hsieh and Klenow, 2009).

Efficiency gains with all inputs. While our empirical estimates of farm productivity take into account all inputs, in our analysis of reallocation gains we abstract from variation in input ratios across farms. This abstraction is conservative on the magnitude of reallocation gains since input ratios may also be distorted across farms. We make this abstraction because part of this variation may be due to technology differences across farms that we are not able to control for as well as differences across farms in the composition of crop production. Nevertheless, we illustrate the quantitative importance of variation in input ratios across farms in each state in our sample in Figure C.1. The x-axis displays our baseline efficiency gains with land input reallocation, whereas the y-axis displays efficiency gains with all inputs. The dashed line is the 45 degree line representing equal efficiency gains in both measures.

Figure C.1: Efficiency Gains across States



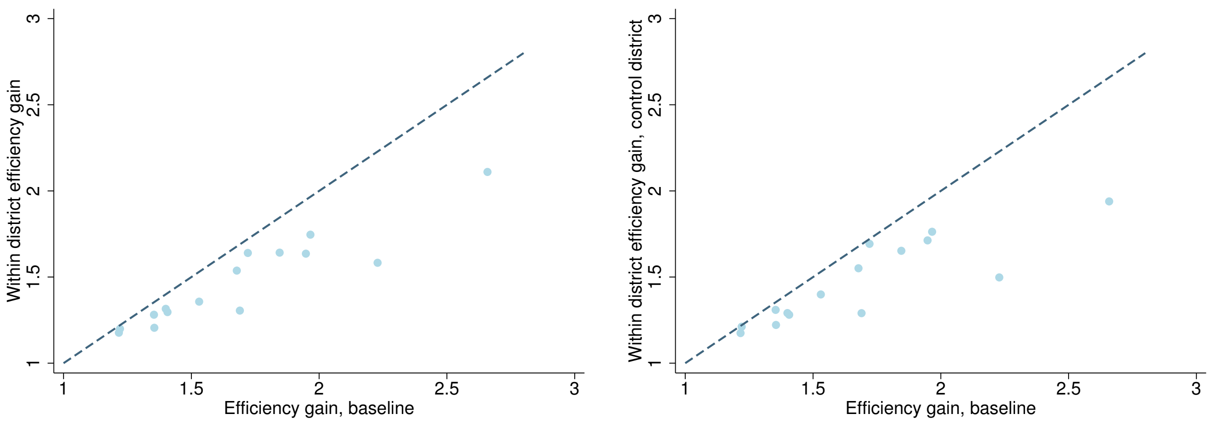
Notes: Efficiency gains in each state with all inputs and with land input (baseline). Data from IHDS wave II 2011-12 (Desai et al., 2012).

As expected, efficiency gains are larger when all inputs are reallocated, but the two measures of efficiency gains are highly correlated (a correlation coefficient in logs of 94%) and the average efficiency gains with land input represent 69% (log(1.68/log(2.13)) of the average overall gains with all inputs. This result echos similar findings for the agricultural sector in other contexts (Adamopoulos et al., 2022; Chen et al., 2023) and the limited relevance of capital-to-labor ratio differences across manufacturing plants in China, India, and the United States documented in Hsieh and Klenow (2009).

Efficiency gains within districts. A potential concern with our farm-level productivity measure is that it does not control for land quality differences. Unfortunately, our dataset does not have land quality measures at the farm and sub-region levels. We address this issue in two ways. First, we discuss evidence in other contexts where land quality differences are found to be a small portion of overall differences in farm productivity. For instance, Chen et al. (2023) analyze detailed micro data for Malawi with land quality dimensions at the plot level. They document an expected pattern that land quality differences are larger across geographical dispersed areas with land quality variation dropping by half from the region level to the district level. Similar finding in less granular data is found in Adamopoulos and Restuccia (2022). Moreover, Adamopoulos et al. (2022) and Adamopoulos and Restuccia (2020) find that variation in land quality across villages account for a small portion (around 1 to 2%) of the variation in farm productivity in China and the Philippines.

Second, motivated by the evidence of larger differences in land quality across more dispersed geographical areas, we provide measures of efficiency gains that restrict reallocation to the district level within a state. For each district in a state and using our baseline measures of farm productivity that adjust for state-level effects, we compute the efficient allocation of land and the corresponding agricultural output, and then aggregate these outputs for all districts in a state. Efficiency gains within districts is just the aggregate efficient output in all districts in a state relative to actual aggregate output in the state. This measure is equivalent to an output weighted measure of district efficiency gains in a state and we refer to this measure as simply within district efficiency gain in each state. Figure C.2, panel A, documents the efficiency gain within districts against our baseline measure of efficiency gains for each state. The efficiency gains are strongly correlated (correlation coefficient in logs of 0.93) and in average the within district efficiency gains represent 74% (log(1.468)/log(1.68)) of the average baseline efficiency gains.

Figure C.2: Efficiency Gains within Districts in each State



Notes: Efficiency gains of within district reallocation when farm productivity controls for state-level effects and district-level effects. Data from IHDS wave II 2011-12 (Desai et al., 2012).

In addition, we also conduct an alternative measurement of farm productivity that adjusts for district-level effects as opposed to state-level effects as in our baseline measure. The idea with this alternative estimate is that the farm TFP residual at the district level removes potential variation in land quality across districts within a state. Note of course that district-level effects may be removing real productivity variation across districts that is not related to land quality and as a result the alternative estimates are an upper bound of the importance of land quality differences across districts. We use the individual fixed-effect from equation (**??**), $\ln a_{is}$, where s indexes the state that farmer i belongs to. Since we have information on the district d that farmer i belongs to, in the second step, we remove from the individual farm fixed effect the district level instead of the state level by running a regression as follows with district dummies:

$$\ln a_{is} = \ln a_d + \ln z_{id}. \tag{C.3}$$

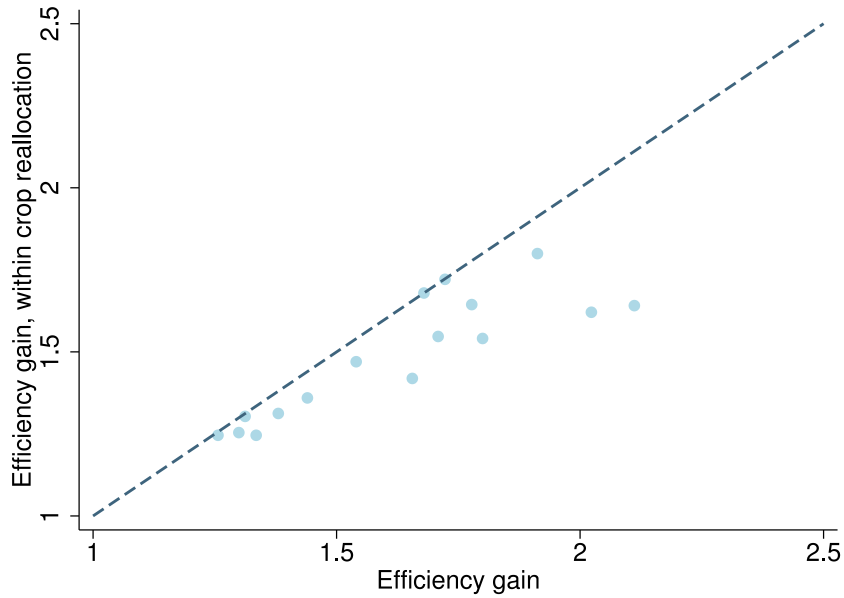
We use the residual $\ln z_{id}$ from the above specification as an alternative measure of farm TFP that excludes district-level productivity differences inclusive of land quality effects within a state. As in the previous analysis, we also only reallocate land efficiently within a district in a state and report the within district efficiency gain in this measure.

Figure C.2, panel B, plots efficiency gains in each state using our baseline measure of farm TFP z_{is} against the alternative measure of farm TFP z_{id} that controls for district and time fixed effects and hence controls for potential differences in land quality across districts. The results are consistent with our previous findings in that efficiency gains are strongly correlated (correlation coefficient of 0.88) and in average the within district efficiency gains represent 74% (log(1.465)/log(1.68)) of the average baseline efficiency gains.

Robustness on within crop reallocation. We evaluate the robustness of efficiency gains when reallocation is restricted to farms with similar crop production in a state. Since crop-level output data is available only for wave I, we restrict this analysis to the wave I (2004-05) instead of wave II (2011-12) as in the baseline. Our baseline efficiency gains are recalculated for the wave I data.

To characterize within crop reallocation, we first classify farms as producing a crop if more than half their estimated revenue is generated by one crop. From this set, we then restrict only the crops which are being produced by at least 10 households in a state in the (unweighted) sample. This leads to 29% of household level observations being dropped from the final sample. Note that the crop selection procedure results in states having different sets of crops. For example, Assam has only one crop that is produced by at least 10 households, while Karnataka has 14 different crops. We then expand our data using the household weights to carry out the reallocation exercises. In each state and for each crop, we compute the efficient allocation of land across farms within a crop. We then aggregate these gains at the state level to represent the within crop efficiency gain in each state. Figure C.3 documents the within crop efficiency gain against the baseline efficiency gain in a state.

Figure C.3: Efficiency Gains within Crops in each State



Notes: Efficiency gains when reallocation is only within a crop in a state against the baseline efficiency gains in each state (same sample). Data from IHDS wave I 2004-05 (Desai et al., 2005).

We find that these alternative measures of reallocation gains are strongly correlated (correlation coefficient in logs of 0.90) and that the within crop efficiency gains represent 82% (log(1.488)/log(1.62)) of the average baseline efficiency gains.

Robustness with respect to γ. We evaluate the robustness of farm-level TFP and misallocation measures on the value of decreasing returns to scale parameter γ. We consider two alternative values of γ from the baseline 0.75 to 0.70 and 0.80. For each value of γ, we recalculate farm-level TFP, distortions, and misallocation measures. We find that our measures of farm-level TFP are not too sensitive to reasonable values of γ, for instance for India the standard deviation of log TFP is 0.626 with baseline $\gamma = 0.75$ and changes to 0.638 with $\gamma = 0.70$ and 0.617 with $\gamma = 0.80$. The reason for this result is that land varies much less across farms than the variation in output, and our fixed effect procedure eliminates level differences. As a result of this, and the fact that land input is given by data, the elasticity of land with respect to farm TFP is relatively unaffected by changes in γ as documented in Figure C.4 for farmers that participate in the land rental market.

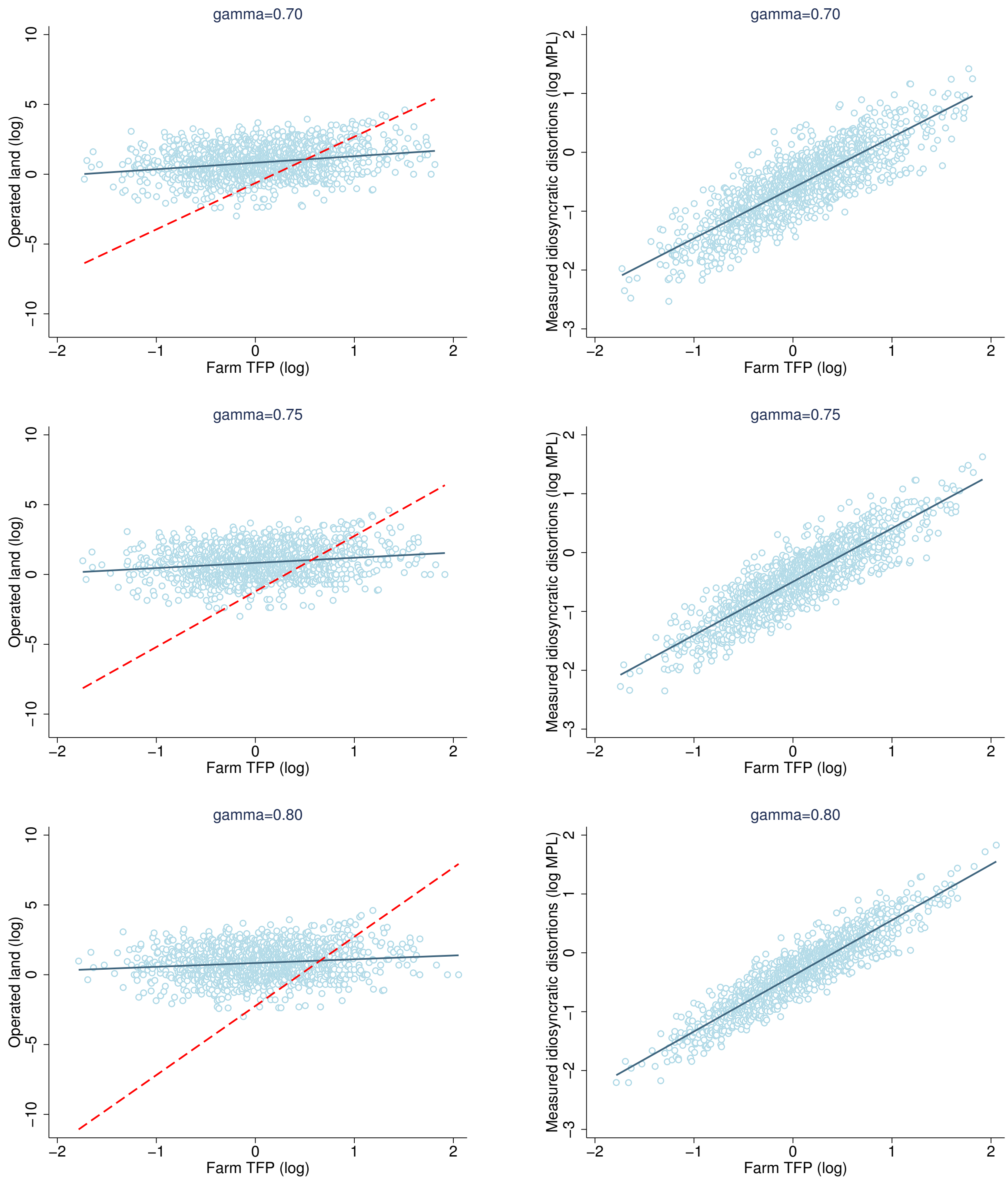
Changes in γ have a larger impact on the efficient allocations given a distribution of TFP since higher γ would require more reallocation of inputs to productive farms to equalize marginal products. But the differences in standard measures of misallocation are relatively small as documented in Figure C.4. For example, the elasticity of distortions with respect to farm TFP changes from 0.91 in the baseline $\gamma = 0.75$ to 0.87 with $\gamma = 0.70$ and 0.94 with $\gamma = 0.80$. These changes are small when compared to the elasticity implied in the efficient allocation of 3.3 with $\gamma = 0.70$ and 5 with $\gamma = 0.80$.

More importantly, our analysis emphasizes differences across Indian states and while changes in the production function can affect the level in measures of misallocation, ranking differences across states are robust to variation in γ. Figure C.5 reports changes in measures of misallocation in each state for the alternative values of γ. We also note that efficiency gains are not necessarily monotone with respect to changes in γ since as reported previously γ has opposing effects on the variance of TFP and efficient allocations, see Hopenhayn (2014) for a broader discussion of this point.

D Model Details

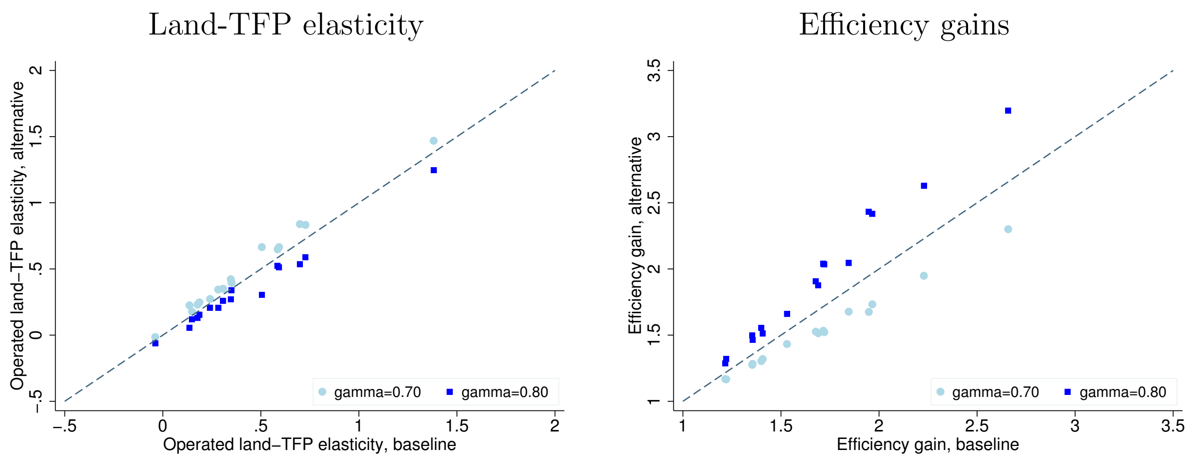
We provide details of the algorithm used to solve the competitive equilibrium, the procedure to calibrate land distortions to data moments for each state, and other results of the quantitative analysis.

Figure C.4: Land, Distortions, and Productivity



Notes: The first-column figures report the relationship between farm land and TFP for farmers participating in the land market in India for alternative values of γ, where $\gamma = 0.75$ is our baseline calibration. The red dashed line is the efficient slope for reference. The second-column figures report the relationship between measured farm distortions and TFP. The solid line is the best fit. Data from IHDS wave I 2004-05 (Desai et al., 2005).

Figure C.5: Misallocation Measures and γ



Notes: Panel A reports the land-TFP elasticity across farms in each state and Panel B reports efficiency gains in each state.The x-axis represents the value in the baseline $\gamma = 0.75$ case, whereas the y-axis represents the alternative values ($\gamma = 0.70$ in circles and $\gamma = 0.80$ in squares).

D.1 Solving for the Competitive Equilibrium

Each state is characterized by the number of farms F_s, total cultivated land L_s in IHDS-II, and farm-level productivity and land endowment $\{z_{is}, \bar{\ell}_{is}\}$ for each farmer in the state.[2] We use the following algorithm to solve for the competitive equilibrium in each state given distortions parameters θ_s, τ_s, and $\sigma_{\epsilon s}$:

1. For each farm, draw $\epsilon_{is} \sim N(0, \sigma^2_{\epsilon s})$.

2. Compute the marginal product of land at the endowment $MPL_{\bar{\ell}_{is}} = \gamma z_{is} \bar{\ell}_{is}^{\gamma-1}$.

3. Guess land price q_s (as initial guess we use the land price associated with the efficient allocation) and compute:

   - $\ln q^{in}_{is} = \ln q_s + \theta_s \ln z_{is} + \epsilon_{is}$,
   - $\ln q^{out}_{is} = \ln q_s + \theta_s \ln z_{is} + \epsilon_{is} - \ln \tau_s$.

[2] We adjust land endowment as a proportion of total cultivated land in each state.

4. Partition farms into three sets and compute land demand ℓ_{is} for each farm:
   - $\ell_{is} = \left(\frac{\gamma z_{is}}{q_{is}^{in}}\right)^{\frac{1}{1-\gamma}}$, if $\ln MPL_{\bar{\ell}_{is}} > \ln q_{is}^{in}$,
   - $\ell_{is} = \left(\frac{\gamma z_{is}}{q_{is}^{out}}\right)^{\frac{1}{1-\gamma}}$, if $\ln MPL_{\bar{\ell}_{is}} < \ln q_{is}^{out}$,
   - $\ell_{is} = \bar{\ell}_{is}$, if $q_{is}^{in} \geq \ln MPL_{\bar{\ell}_{is}} \geq \ln q_{is}^{out}$.
5. Compute relative excess land demand as $f = \frac{\sum_{i=1}^{F_s} \ell_{is}}{L_s} - 1$.
6. If $abs(f) < tol$, done. Otherwise, adjust q_s and repeat steps 3 to 6 until convergence.

D.2 Estimation of Land Distortions

We describe the details of the procedure we follow for estimating the parameters of land market distortions τ_s, θ_s, and $\sigma_{\epsilon s}$ in each state.

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

- If $\tau_s = 1$, all farmers participate in the land rental market, hence the share of farmers not participating in the land rental market provides variation to identify τ_s.
- If $\tau_s = 1$ and $\theta_s = 0$, the covariance between $\ln MPL_{is}$ and $\ln z_{is}$ equals zero, hence this covariance provides variation to identify θ_s, conditional on τ_s.
- If $\tau_s = 1$, $\theta_s = 0$, and $\sigma_{\epsilon s} = 0$, the variance of $\ln MPL_{is}$ equals zero, hence this variance provides variation to identify $\sigma_{\epsilon s}$, conditional on τ_s and θ_s.

Given our estimates of farm productivity z_{is}, data on cultivated land by farms ℓ_{is}, and the farm information on participation in rental markets, we use our assumption on the production function to construct the marginal product of land in farms $MPL_{is} = \gamma z_{is} \ell_{is}^{\gamma-1}$ and the participation information to construct an indicator function of non-participation for each farmer $\mathbb{1}(\ell_{is} = \bar{\ell}_{is})$. We use these data to construct the three moments discussed above in each state:

- $M_1^{\text{data}} \equiv \sum_{i=1}^{F_s} \mathbb{1}(\ell_{is} = \bar{\ell}_{is})/F_s$.
- $M_2^{\text{data}} \equiv \text{Cov}(\ln MPL_{is}, \ln z_{is})$.
- $M_3^{\text{data}} \equiv \text{Var}(\ln MPL_{is})$.

Note that conditional on other parameters, τ_s influences M_1, θ_s influences M_2, and $\sigma_{\epsilon s}$ influences M_3.

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

1. Guess initial parameters $(\theta_s, \sigma_{\epsilon s}, \tau_s)$. We use $\theta_s = 0.5$, $\sigma_{\epsilon s} = 1$, and $\tau_s = 1$.
2. For each k of 100 simulations, draw $\{\epsilon_{is}^{(k)}\}_{i=1}^{F_s}$ and solve the competitive equilibrium, and compute the required moments implied by the model:
   - $M_1^{(k)} \equiv \sum_{i=1}^{F_s} \mathbb{1}(\ell_{is}^{(k)} = \bar{\ell}_{is})/F_s$.
   - $M_2^{(k)} \equiv \text{Cov}(\ln MPL_{is}^{(k)}, \ln z_{is})$.
   - $M_3^{(k)} \equiv \text{Var}(\ln MPL_{is}^{(k)})$.
3. Compute simulated moments by averaging moments from the simulations,
$$M_n^{\text{model}} = \sum_{k=1}^{100} \frac{M_n^{(k)}}{100} \quad \text{for each } n = \{1, 2, 3\}.$$
4. Compute distance D_n between data and average simulated moments,
$$D_n = M_n^{\text{data}} - M_n^{\text{model}} \quad \text{for each } n = \{1, 2, 3\}.$$

5. If $\max\{abs(D_n)\} > tol$, adjust parameter guesses and iterate on steps 2 - 5 until convergence.

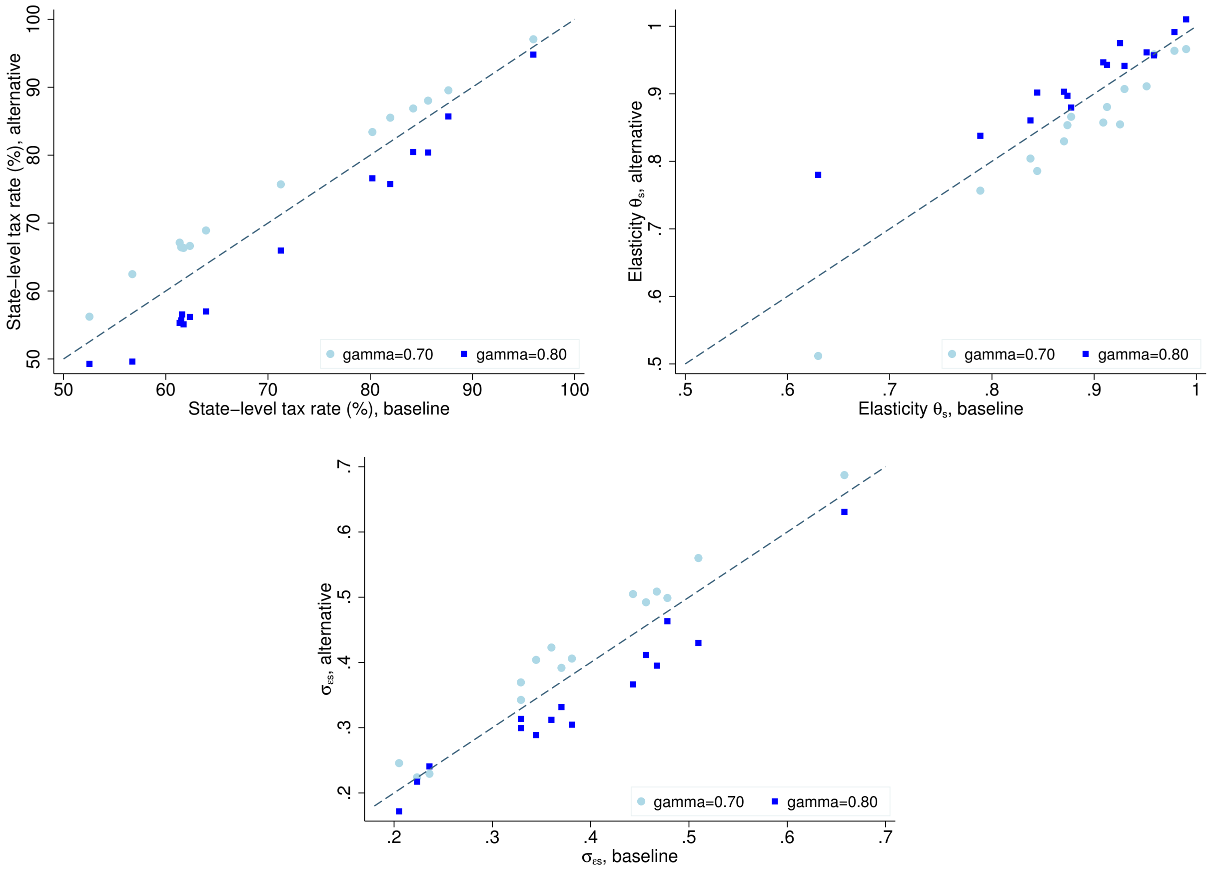
D.3 Model Robustness

We evaluate the robustness of our model results to reasonable variations in the estimated value of the decreasing returns to scale parameter γ. As in the empirical section, we vary the value of γ from 0.75 in the baseline calibration to 0.70 and 0.80, a range of values considered in the misallocation literature.

For each value of γ, we re-estimate farm-level TFP in each state and re-calibrate the parameters of distortions. Figure D.6 reports the differences in estimated parameter values for each state with respect to the baseline values. As a summary, the average estimated value of θ_s changes from 0.89 in the baseline $\gamma = 0.75$ to 0.85 with $\gamma = 0.70$ and 0.91 with $\gamma = 0.80$. Similarly, the state-level tax associated with τ_s changes from 71% to 75% and 66%, and σ_s from 0.39 to 0.42 and 0.35.

For each value of γ we also perform the counterfactual experiments and summarize the contribution of land-market rental barriers τ_s to the overall reallocation gains in Figure D.7. Whereas in the baseline τ_s contributes 51 percent of the efficiency gains for India (land-weighted average across states), the contribution changes to 58 percent with $\gamma = 0.70$ and 42 percent with $\gamma = 0.80$. In a highly distorted state such as Tamil Nadu, the contribution ranges from 87 to 96 percent. As emphasized earlier for other measures of misallocation, ranking differences across states are preserved with alternative values of γ as documented in Figure D.7.

Figure D.6: Land Rental-Market Distortions for Different Values of γ



Notes: Panel A reports the estimated state-level rental barrier τ_s as a tax rate on the rent-in rate, i.e., tax$= (1 - 1/\tau_s)$. Panel B reports the estimated idiosyncratic distortions elasticity θ_s. Panel C reports the estimated distortions dispersion parameter $\sigma_{\epsilon s}$. In all panels, the x-axis represents the value in the baseline $\gamma = 0.75$ case, whereas the y-axis represents the alternative values ($\gamma = 0.70$ in circles and $\gamma = 0.80$ in squares).

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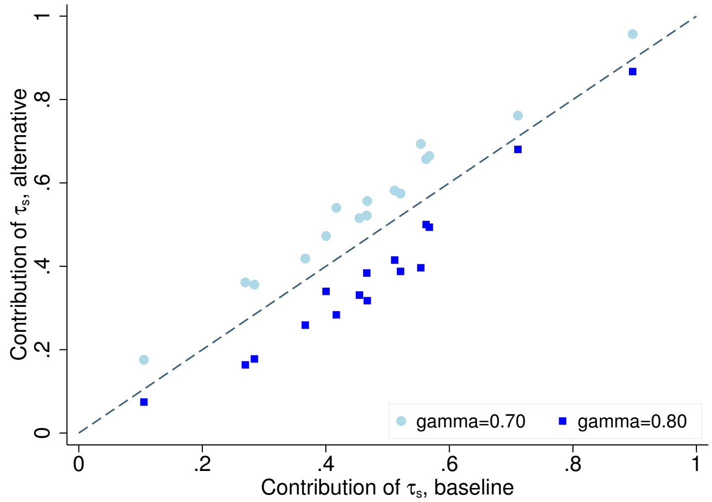
Figure D.7: The Contribution of Land Rental-Market Barriers for Different γ's



Notes: Contribution to reallocation gains in fraction of state-level rental barriers τ_s to reallocation gains. The x-axis represents the value in the baseline $\gamma = 0.75$ case, whereas the y-axis represents the alternative values ($\gamma = 0.70$ in circles and $\gamma = 0.80$ in squares).

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