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Achieving Scale Collectively*

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Abstract

Many firms in developing countries could be too small to adopt modern technology embodied in expensive production machines. This paper shows that rental market interactions allow these small firms to increase their effective scale and mechanize production. We conduct a survey of manufacturing firms in Uganda, which uncovers an active rental market for large machines between small firms in informal clusters. We then build an equilibrium model of firm behavior and estimate it with our data. We find that the rental market is quantitatively important for mechanization and productivity since it provides a workaround for other market imperfections that keep firms small. The rental market also shapes the effectiveness of development policies to foster mechanization, such as subsidies to purchase machines. Overall, our results point to the importance of taking into account firm-to-firm interactions within informal clusters to understand technology adoption in low income countries: focusing on the small scale of firms in isolation might be misleading.

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1 Introduction

Technology is often embodied in large capital inputs, such as production machines, which can be too expensive for small firms to purchase. The small scale of operations of firms in developing countries could thus limit their ability to adopt technology, ultimately hindering their productivity and contributing to the large income gaps that still persist between rich and poor countries (Hall and Jones, 1999; Caselli, 2005; Bloom et al., 2010).

While firms in developing countries are small, they also tend to operate near each other in large informal clusters. In this paper, we show that this feature of their organization improves the ability of small firms to adopt technology and mechanize by increasing their effective scale. To do so, we design and implement a firm survey in urban Uganda, and we interpret the evidence through an equilibrium model. The survey uncovers an active rental market for large machines between small firms. The model reveals that rental markets are effective at increasing mechanization and productivity, thus providing a workaround for other frictions that keep firms small. That is, even when machines are too expensive for each individual firm, rental market interactions allow small firms to *achieve scale collectively* and mechanize.

We surveyed a representative sample of over 1,000 firms in three manufacturing sectors: carpentry, metal fabrication and grain milling. The key innovation of our survey is to collect disaggregated information on the types of capital, labor and managerial inputs used in production. To measure the capital input we collect data at the individual machine-level, such as whether the machine is owned or rented, its price, and hours used. To measure the labor input we gather information on the skills and time allocation of employees. To measure the managerial input we collect information on the business practices of firm owners.

We use the data to describe *how* firms produce output in these sectors, with a focus on the role of scale and mechanization. In doing so, we provide a set of descriptive statistics and empirical relationships that inform our model and are used as targets in its estimation. We include results for all the three sectors, but we focus on carpentry since the role of scale for mechanization is more striking there. We organize the discussion around three key facts.

First, mechanization has clear benefits. While firms produce similar products, they do so at different capital intensity. Some firms rely mostly on labor, while others use modern, electric-powered machines, and this latter group has higher revenues per worker. Second, the small scale of firms limits investment since machines are expensive and have high capacity relative to the size of firms. One example is the thickness planer, a key machine in the production process for carpentry. Thickness planers cost about $4,000, or roughly *18 times* average monthly profits. Not surprisingly, less than 10% of firms own one. Third, the indivisibility of machines is overcome, at least partly, by the presence of an active inter-firm rental market. Back to the example, while less than 10% of firms own a thickness planer, 50% rent one. Renting is primarily between firms in the same sector and cluster, and is possible since machine owners

have substantial excess capacity that they can rent out to other firms.

The extent to which the rental market allows small firms to access large machines depends on whether there are transaction costs that limit its functioning. For this reason, in our survey we collect detailed information on observable transaction costs, such as transportation and time costs, which we show to be significant. We then develop a revealed preference approach to quantify their overall size by comparing the relative utilization of machine hours by renters and owners of machines: we estimate the rental market transaction costs to be approximately 40% of the direct machine rental price.

Motivated by the data, we design an equilibrium model to: (i) quantify the aggregate effects of the rental market; (ii) shed light on the mechanisms through which these effects manifest; and (iii) discuss the lessons for development policy. In the model, individuals draw a managerial ability and a cost of capital and decide how much and how to produce. Managers decide whether to mechanize production and whether to purchase machines or rent them from other firms. If they purchase machines, they also decide how much of their machine's capacity to use for their own production and how much to rent out. The rental market for machines is subject to a transaction cost τ: for every dollar earned by a machine owner, the renter pays $1+\tau$ dollars. All managers produce differentiated products and hire workers subject to a firm-specific increasing cost of labor which captures labor market frictions in reduced form.

We characterize the solution analytically, studying how the rental market shapes the economy. To do so, we analyze how the equilibrium outcomes vary as a function of the transaction cost, which offers a useful summary statistic of how well the rental market works: when $\tau = 0$, the marginal cost of owned and rented capital is identical, while if τ is large enough, the rental market breaks down and firms only access capital through investment in machines.[1] We prove that a rental market with low transaction costs increases the profitability of all active firms and we formalize the two mechanisms through which it operates. The first one is akin to the financial market: by unbundling capital ownership and utilization, a well-functioning rental market improves the allocation of capital since managers with the lowest cost of capital purchase the machine, and the ones with the highest returns use it. The second one is specific to the rental market and conceptualizes the idea of collective scale: in the presence of strong decreasing returns and high-capacity machines, the equilibrium scale of firms may not be large enough to justify the investment if firms must use all the capacity themselves. The rental market allows firms to share machine capacity, thus overcoming this problem. Even when all managers are identical so that the rental market has no allocative role by construction, a well-functioning rental market increases mechanization by allowing more firms to access the same machines.

[1] There may be other reasons why rental markets may not function properly or fail to emerge, such as market leaders leveraging their dominant position and deciding not to rent out machines to competitors. Such strategic considerations were not first order in our context characterized by many small firms facing strong decreasing returns, but may well be relevant in other environments with more direct competition between fewer producers.

We next bring the model to the data and use it to study the role of rental markets for economic development. We show that the model delivers our estimated transaction costs τ as a structural parameter. The remaining parameters are estimated by simulated method of moments, targeting the empirical relationships related to the three key facts mentioned above.

On the aggregate, eliminating transaction costs in the rental market ($\tau = 0$) increases mechanization by 192%, labor productivity by 12.4%, and output by 17.5% relative to an economy where renting is not possible. The benchmark economy, where we estimate $\tau = 0.430$, attains more than half of the possible gains. This shows that the rental market is quite effective despite the documented transaction costs, thus allowing firms to *achieve scale collectively.* Two features of our estimates are key to generate these substantial aggregate gains: (i) mechanization embeds large productivity gains; and (ii) the capacity of machines is large relative to the small size of firms, so that machine owners have excess capacity to rent out.

Turning to the mechanisms, we use the model to shed light on why rental markets matter, and when and where they do. All firms benefit from a reduction in transaction costs, as a well-functioning rental market allows more firms to access machines, overcoming the indivisibility through collective scale. At the same time, managers with a high cost of capital benefit disproportionally since the rental market unbundles ownership and utilization. Managers operating at relatively lower scale also benefit more since the indivisibility is particularly binding for them. The rental market is prevalent and important in our setting because it creates a workaround for other market imperfections that we estimate to be large, such as frictions in the financial, labor and output markets. Our results imply that we should expect rental markets to become less prevalent as countries develop.

We also use the model to perform policy experiments and study how the effectiveness of development policies aimed at increasing mechanization depends on the rental market. The presence of the rental market reduces the effectiveness of subsidies to purchase machines. Comparing the distributional effects of subsidies to purchase and rent machines, we find that providing a mix of both can be an equitable policy to raise mechanization and productivity for all types of firms. Finally, in our context, equilibrium effects cannot be ignored: the productivity gains that could be estimated by partial equilibrium randomized experiments offer misleading evidence on the effect of policies at scale.

Related Literature. Our work speaks to three topics in economic development. First, we contribute to a large literature on the role of fixed costs in production, often generated by capital embodied technology, and the potential for poverty traps (Banerjee and Duflo, 2005; Kaboski and Townsend, 2011a; Balboni et al., 2021; Banerjee et al., 2021; Bari et al., 2021).[2] Our contribution here is twofold. By exploiting our unique data on capacity utilization, we

[2] Griliches (1997), Janes et al. (2019) and Caunedo and Keller (2021) study capital embodied technology.

provide direct evidence that capital indivisibility is an important source of scale economies. In doing so, we also build on a classic literature that studies economies of scale in the early phases of U.S. industrialization (Atack, 1978, 1985; Chandler, 1990; Atack et al., 2008).[3] Further, we uncover how small firms in informal clusters are able to overcome large fixed costs and to invest in technology through a rental market for machines, and how this limits the productivity costs of small scale and the risk that firms remain stuck in poverty traps.

Second, we bring new perspectives to a broad literature on the role of financial frictions in creating misallocation and impeding entrepreneurship and growth (Greenwood and Jovanovic, 1990; Midrigan and Xu, 2014; Buera et al., 2011a, 2017). Our contribution is to show how the rental market reduces capital misallocation by reallocating machine capacity across firms. As the rental market provides a workaround for financial frictions, our results imply that the aggregate cost of financial frictions might be, in certain contexts, lower than previously estimated.

Third, our work sheds new light on the well-accepted notion that the firm size distribution in developing countries is dominated by small firms (Hsieh and Olken, 2014; Hsieh and Klenow, 2014).[4] This classic result hinges on using the managerial span of control to define the boundary of the firm (as in Lucas (1978)). As we estimate limited transaction costs in the rental market, this motivates us to redefine a firm as all the workers using the same machines. Doing so, the firm size distribution changes dramatically in our data: the share of firms with more than 10 employees goes from 5% to 33%. Many before us have conceptually challenged the notion that managerial control defines the size of the firm.[5] Our contribution is to offer a case study that highlights how redrawing the firm boundaries may change our view on the firm size distribution. To our knowledge, we are the first to do so in a low-income country, which is particularly relevant due to the prevalence of small firms.

We are not the first to study rental markets for capital. Rampini (2019) discusses the role of renting in a model of financing for durable assets, and Rampini and Townsend (2016) bring evidence from Thai households. More recently, Caunedo et al. (2020) and Caunedo and Kala (2021) study rental markets for agricultural equipment in India, focusing on congestion and transportation costs in the rental market. Our main contribution is to highlight that the rental market allows small firms to achieve scale collectively, helping them to overcome barriers to technology adoption and access large capital equipment.

We are also not the first to study informal clusters in developing countries and to claim that

[3] In more recent work in developing countries, Foster and Rosenzweig (2022) show the importance of indivisible capital in farming, although they lack data on capacity utilization. Jensen and Miller (2018) also suggest that larger firms use capital more effectively, but cannot show direct evidence due to data limitations.

[4] Hsieh and Olken (2014) show the prevalence of small firms, and De Mel et al. (2008), Banerjee and Duflo (2014), Jensen and Miller (2018), Hardy and McCasland (2020), De Mel et al. (2019) and Akcigit et al. (2021) are recent studies on constraints to firm expansion in developing countries.

[5] See Coase (1937); Richardson (1972); Chandler (1977); Grossman and Hart (1986) and Hart and Moore (1990). Empirically, Olmstead and Rhode (1995) describe how cooperative exchanges for reaper services among farmers in the United States contributed to their rapid diffusion.

they can play an important role for productive efficiency.[6] This is an old idea that goes back at least to Marshall (1920). More recent work at the intersection of sociology and economics has provided interesting case studies (Rabellotti, 1995; Schmitz, 1995). Our contribution is to provide the first quantitative assessment of physical firm-to-firm interactions in determining access to modern technology.[7] In doing so, we also highlight that interactions in the rental market for capital can be an important source of economies of agglomeration, thus providing a useful micro-foundation for the large urban literature on agglomeration (Duranton and Puga, 2004; Ellison et al., 2010).

Structure of the paper. Section 2 discusses the sampling strategy and survey design. In Section 3 we present key facts on the organization of production and the rental market, and develop an empirical strategy to estimate the size of transaction costs. The model is developed in Section 4, and Section 5 discusses identification and estimation. Section 6 quantifies the aggregate effects of the rental market, the mechanisms through which these effects arise, and the implications for development policy. Additional results are in the Online Appendix. A Supplemental Appendix not intended for publication can be found on the authors' websites.

2 The Survey

The survey took place in late 2018 and early 2019, and was implemented by our partner NGO, BRAC Uganda, in partnership with the Ministry of Trade, Industry and Cooperatives in Uganda. In this section, we present the key elements of the sampling strategy and the survey instrument.

Sampling. Our survey targeted firms in manufacturing, where output is easier to measure and where both capital and labor are relevant inputs. Within manufacturing, we focused on three prominent sectors: carpentry, metal fabrication and grain milling. As revealed by the latest Census of Business Establishments conducted by the Uganda Bureau of Statistics in 2010, these are sectors that: (i) employ a large share of workers and (ii) are not dominated by micro-enterprises. We thus target sectors that are important for policy, and we focus on sectors where both small and large firms co-exist.

The survey was implemented in a representative sample of urban and semi-urban areas across three of the four macro-regions of Uganda: Central, Western, and Eastern regions. A sample of 52 sub-counties was randomly extracted, stratifying by population and by whether the sub-county is in the broader Kampala area. We conducted an in-person door-to-door listing

[6] For instance, Atkin et al. (2017) study clusters of soccer ball producers in Pakistan; Rabellotti (1995) describes clusters of footwear enterprises in Mexico; Shapiro et al. (2020) study clusters of carpenters in Kenya.

[7] Cai and Szeidl (2018) and Perla and Tonetti (2014) study firm-to-firm knowledge spillovers.

of all the firms in our three sectors in the sampled areas, identifying close to 3,000 firms. We randomly extracted about 1,000 firms from our listing to be included in the survey, oversampling firms with five or more employees, to ensure coverage of a sufficient number of relatively large firms. In firms selected for the survey, we interviewed the owner and all the employees working on our pre-specified core products, which are discussed below. Across the three sectors we interviewed 1,115 firm owners and 2,883 employees. Compliance with the survey was high at over 90%. All our results are weighted to reflect our sampling strategy.

Survey design. Our objective was to zoom inside the firm, and paint a complete picture of how capital and labor inputs are combined to produce output. Following existing surveys, we collected a wide range of firm-level information such as revenues, number of employees, wages, owner and employee characteristics (e.g., age, education, experience, and training). Following McKenzie and Woodruff (2017), we also measured the managerial practices of the owner, using a battery of questions about record keeping, marketing, stock control, business performance review and financial planning, which are combined into a continuous index of managerial ability.

We then went beyond related studies and collected information on the entire production process for key products. This allows us to improve on the measurement of capital and labor, and how they are combined. We worked with the Uganda Industrial Research Institute to identify one "core product" made by most firms for each sector. These are: doors in carpentry, windows in metal fabrication, and maize flour in grain milling. We then broke down the production process of these products into a series of steps that firms typically engage in, and collected information on: (i) whether firms produce the pre-specified core product; (ii) whether they perform the pre-specified production steps; and (iii) the combination of capital and labor used in each step. In particular, for each step we know whether this is performed using modern electric-powered machines or manual tools, which employees work on the step and for how many hours, and the time taken by the employee (or team of employees) to complete it.

For each machine, we collected numerous details, including whether it is owned or rented, the purchase (or rental) cost, and measures of capacity utilization: for both machine owners and renters we know how many hours per week they use each machine in production, and machine owners were also asked how many hours they rent out each of their machines to other firms. Finally, for our core products we collected information on: quantities produced and sold, prices, and multiple proxies of quality measured through direct observation by our enumerators.[8]

[8]Further details on the sampling strategy and survey design are provided in the Supplemental Appendix. There we also (i) discuss the administrative units of Uganda, (ii) clarify that some of the descriptive evidence on rental markets presented later in the paper was captured in brief follow-up surveys with our sample of firms in the months after the initial survey, and (iii) provide more details on the classification of core products and the measurement of the production process.

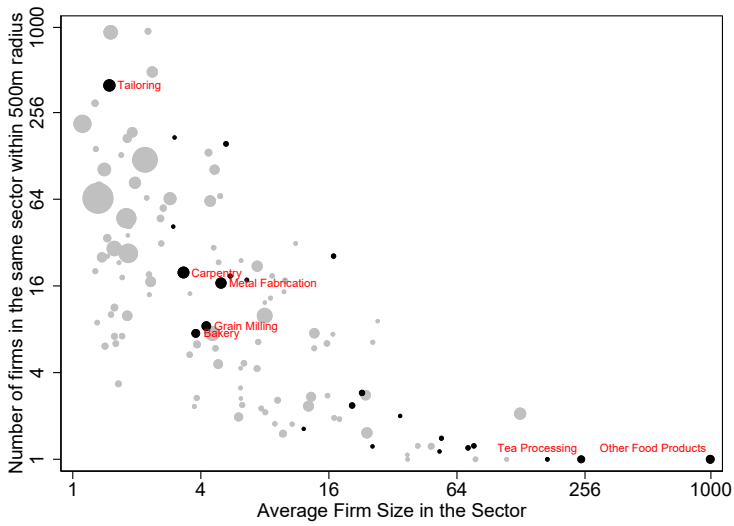
3 The Organization of Production in Urban Uganda

In this section, we describe how production is organized in our three sectors, with a focus on the role of scale, mechanization, and rental markets for machines. In doing so, we highlight a number of key facts and statistical relationships that inform and discipline our model. We then develop an empirical strategy to estimate the size of transaction costs in the rental market.

3.1 Descriptives on the Anatomy of Production

We begin by describing how production is carried out, with a focus on the output that is produced, the production process that is used, and the extent to which there are differences across firms and sectors. To this end, we highlight a number of key descriptive statistics for our sample of firms, reported in Table 1. Additional descriptives can be found in the Online Appendix, and further details on the descriptives summarized in this section are in the Supplemental Appendix.

Figure 1: Spatial concentration of firms across sectors in Uganda



Notes: Data from the Census of Business Establishments (2010) for Uganda. For each firm, we compute the number of other firms in the same 3-digit industry located at a distance below 500 meters. We then plot the within industry average as a function of average firm size. The size of each dot is proportional to the number of workers in the industry. Black dots are industries in manufacturing. We drop sectors that employ less than 1,000 individuals across Uganda, and omit one clear outlier.

Many small firms operate in informal clusters. Production takes place in a large number of small firms. Panel A shows that the average firm is small, employing about 4.5-6 workers across sectors. However, the average firm operates well beyond subsistence, with monthly revenues per worker between \$233-\$278. To put these numbers into perspective, per capita GDP in Uganda was \$60 per month in 2018. We identified close to 3,000 firms in our listing,

with hundreds of firms in each sector. These numerous small firms are concentrated in clusters. One way to see this is to use our listing to calculate the average number of firms in the same sector within a 500 meter radius from each firm in the survey. These are: 26 firms in carpentry, 9 in metal fabrication and 15 in grain milling, thus confirming that there is substantial spatial clustering. Using the latest available official firm census for Uganda, Figure 1 shows that the geographical proximity of firms is a systematic feature of production in our setting, especially in sectors where firms are small (and our target sectors are not outliers).

Table 1: Descriptives on the anatomy of production in the three sectors

	Carpentry		Metal fabrication		Grain milling	
Number of surveyed firms	522		433		160	
	Mean	[Q20 ; Q80]	Mean	[Q20 ; Q80]	Mean	[Q20 ; Q80]
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Basic firm characteristics						
Number of employees	4.5	[2.0 ; 6.0]	4.9	[3.0 ; 6.0]	6.0	[3.0 ; 8.0]
Monthly revenues per worker (USD)	233	[64 ; 373]	278	[103 ; 439]	241	[49 ; 439]
Monthly profits per worker (USD)	42.3	[9.2 ; 68.0]	46.7	[12.6 ; 76.3]	32.6	[8.8 ; 47.6]
Employee monthly wage (USD)	73.8	[38.2 ; 98.7]	71.6	[39.5 ; 92.1]	52.3	[25.4 ; 73.4]
Owner years of education	9.8	[7.0 ; 13.0]	10.0	[7.0 ; 13.0]	10.9	[7.0 ; 16.0]
Manager ability	11.2	[6.0 ; 16.0]	10.9	[5.0 ; 16.0]	11.8	[5.0 ; 18.0]
Number of other firms within 500m	26.5	[3.0 ; 55.0]	9.1	[3.0 ; 11.0]	15.3	[0 ; 51.0]
Panel B: Core product and production steps						
Share of firms making core product	0.68	-	0.92	-	0.93	-
Revenue share of core product	0.35	[0.17 ; 0.53]	0.36	[0.22 ; 0.48]	0.66	[0.38 ; 0.97]
Share of production steps performed	0.76	[0.60 ; 0.90]	0.89	[0.86 ; 1.00]	0.60	[0.43 ; 0.71]
Panel C: Machine utilization on core product						
Number of machine types used	5.4	[2.0 ; 8.0]	3.6	[2.0 ; 5.0]	3.1	[2.0 ; 4.0]
Number of machine types rented	3.4	[0.0 ; 6.0]	0.5	[0 ; 1.0]	0.1	[0 ; 0]
Value of avg. machine used (USD)	1,642	[240 ; 1,830]	221	[101 ; 213]	871	[421 ; 1,237]
Weekly hours of avg. machine used	9.1	[1.9 ; 13.0]	17.8	[3.7 ; 30.3]	44.6	[26.5 ; 62.5]

Notes: Means and 20th-80th quantile ranges. Sample: surveyed firms. All statistics are at the firm level. For the statistics from row 6 (Revenue share of core product) onwards, the sample is restricted to firms producing the core product (doors, windows, and maize flour, respectively). Monthly revenues: average revenues in the three months preceding the survey. Manager ability: index going from -1 to 27 and based on multiple survey questions; see the Supplemental Appendix for details. The number of other firms within a 500m radius is calculated using the initial listing and considers firms operating in the same sector. Average weekly machine hours refer to utilization on the core product for own production, and are conditional on positive hours. Conversion rate: 1 USD = 3,800 UGX. Revenues, machine values and number of employees are trimmed at the top 1%.

Firms produce similar products. Panel B shows that the large majority of firms engage in the production of the pre-specified core product, and the core product makes up a large share of monthly revenues for the average firm, corresponding to 35%-66% across sectors. In addition, firms producing the core product engage in the majority of the pre-specified production steps, with little variation across firms. In short, firms produce similar products using similar production steps, so that we do not find evidence of significant specialization across firms. The similarity of products and production steps across firms is notable in that it opens up the possibility that firms could share the same machines in production.

Dispersion in mechanization, size, and productivity across firms. Although firms produce similar products using similar steps, we find substantial heterogeneity in mechanization of the production process for the core product. This is possible because the same production steps can be performed either with modern machines or with manual tools. As shown in Panel C, there is variation across firms both in the number and value of machines used. For instance, in carpentry, while the average firm uses five machines, firms at the 20th (80th) quantile use two (eight) machines. In addition, we document substantial dispersion in size and productivity in Panel A. For example, while the average carpentry firm has 4.5 employees, the 20-80 quantile range goes from two to six employees. We find similar dispersion in revenues per worker, profits per worker and managerial ability.

Sectoral heterogeneity in mechanization, size and productivity. The average firm across our three sectors is broadly similar in terms of number of employees, wages, managerial ability, revenues/profits per worker and number of other firms located nearby (Panel A). This highlights how the clustered nature of production and the competitive environment are similar across sectors. Instead, the three sectors are different in the cost of the machines needed in production and the number of machines used (Panel C). In carpentry, machines are expensive (the average machine costs over seven times average monthly profits), and multiple machines are used, each for a few hours. In the other two sectors machines are cheaper, fewer machines are used, and each is operated more intensively. These results are in line with technological differences in the production process across sectors and highlight how the role of scale for mechanization may be particularly important in carpentry, where firms are small but the mechanized production process involves multiple expensive machines. A rental market for machines may therefore be more useful in carpentry. Indeed, Panel C shows that rented machines are much more prevalent there. In the rest of the paper, we focus primarily on carpentry, as our interest is in understanding the role of the rental market in helping firms overcome barriers to the adoption of capital equipment that is large and expensive relative to the size of firms. This sectoral comparison highlights how taking into account features of the production process

is important to understand the prevalence of rental markets across the developing world: the rental market can emerge if firms are small relative to the capacity and cost of the machines needed in production.

Labor and output markets. Before turning to the market for capital, we present some descriptive evidence on the labor and output markets to characterize the economic environment where firms operate, and to inform our model. On the labor market, our survey reveals that: (i) labor market frictions are an important perceived constraint for managers, especially difficulties in screening workers; (ii) hiring happens mostly through referrals; (iii) task specialization among workers increases only weakly with the size of the firm; and (iv) larger firms pay higher wages. This evidence is consistent with limited economies of scale driven by labor specialization, and with the cost of recruitment increasing with firm size due to labor market frictions, as in frictional labor models with monopsony wages such as Burdett and Mortensen (1998) and Heise and Porzio (2021). On the output market, we find evidence of imperfect competition due to: (i) firms producing different *varieties* of the same product (e.g., doors of different quality), and (ii) output market frictions related to largely local demand and the importance of social connections with customers. Consistent with this, we estimate markups of 23% in the carpentry sector, and consider monopolistic competition in the model. More details are reported in the Online Appendix.

3.2 Mechanization, Scale, and Rental Markets

We now describe the importance of mechanization for productivity, the role of scale for mechanization, and the role of the rental market for machines. We organize the discussion around three facts. While doing so, we produce a set of empirical correlations. We do not argue that these relationships are causal, but they will provide a set of empirical targets for the model's estimation. Through the model, we will be able to provide a precise quantitative interpretation of the strength of these correlations. As discussed above, from now on we focus on carpentry as that is the sector where the role of scale for mechanization is more striking.

Fact 1: Mechanization Improves Firm Productivity

We study the correlation between mechanization and productivity. In the survey, firms were asked to indicate which of 23 pre-specified machine types they use in the production of their core product (doors). For each firm, we construct their "mechanization rate", defined as the share of such machines used.[9] We regress revenues and revenues per worker on the mechanization rate, using the sample of carpenters who produce doors, our core product. The results are reported

[9] In constructing the mechanization rate, each machine type is weighted using the share of total machine time it accounts for in the data, so that machines used more heavily in our sample get a higher weight.

in Table 2. Columns 1 and 4 show a strong positive correlation between mechanization and both revenues and revenues per worker. These regressions control for sub-county fixed effects, and so do not just capture the sorting of more productive managers to more productive areas where machines may be more easily accessible.

Mechanization is not the only relevant correlate of revenue productivity. In fact, as shown in columns 2 and 5 of Table 2, there is a strong positive correlation between our managerial ability index and productivity: a one standard deviation increase in the index is associated with a 29% increase in revenues and a 14% increase in revenues per worker. In columns 3 and 6 we include both the mechanization rate and the managerial ability index at the same time, and find that both remain strong predictors. This indicates that the correlation between mechanization and productivity in column 4 does not just capture the fact that high ability managers are better able to use machines or have easier access to capital.[10]

Table 2: The role of mechanization and managerial ability for revenue productivity

	Log Revenues			Log Revenues p.w.		
	(1)	(2)	(3)	(4)	(5)	(6)
Mechanization Rate (0-1)	1.693		1.530	1.268		1.195
	(0.267)		(0.260)	(0.255)		(0.261)
Manager Ability (Std.)		0.288	0.250		0.144	0.114
		(0.049)	(0.047)		(0.047)	(0.047)
Sub-county FE	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.509	0.494	0.547	0.435	0.405	0.442
Observations	378	378	378	378	378	378

Notes: OLS regression coefficients, robust standard errors in parentheses. Sample: door producers. Outcomes: Log monthly revenues (columns 1-3) and log monthly revenues per worker (columns 4-6). Mechanization rate: share of pre-specified machine types for the production of core product that are used by the firm. Managerial ability: standardized index based on multiple survey questions; see the Supplemental Appendix for details.

Fact 2: Small Firm Scale Limits Investment

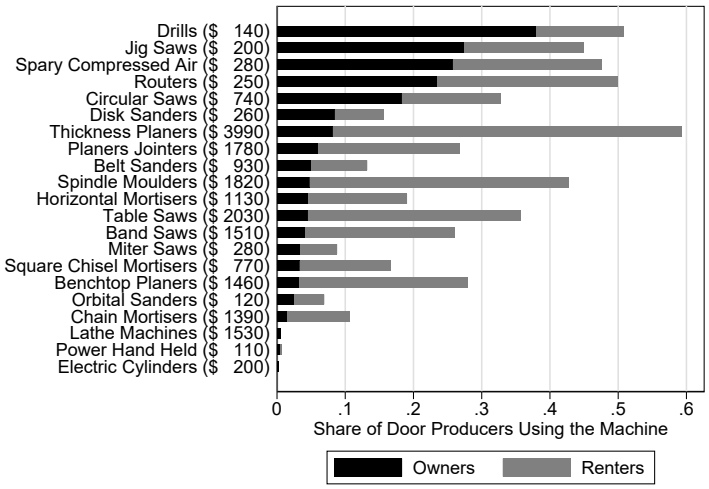
Figure 2 shows the percentage of firms using each type of machine in the production of doors, together with their average price. Most machines are expensive: for example, thickness planers, a key machine in the door production process, cost $4,000 on average – about 18 times average

[10]We further unpack the correlation between mechanization and revenue productivity, and find that this is due to both an increase in physical productivity and output quality. Using data on the time taken to complete a production step, we find that steps in which machines are used can be completed 17% faster on average (and this result is robust to a large set of controls). We also document a strong positive correlation between mechanization and our direct measures of output quality and prices. However, there is no correlation between mechanization and markups, which confirms that the higher prices reflect higher quality. See the Supplemental Appendix for more details.

monthly profits ($220). In terms of the retail market for machines, 92% of the machines used in door production are imported, and the majority of machine owners report typically buying machines from domestic intermediary retailers. Most machines have a capacity that is too high for a single firm. Consequently, even firms that use machines do not use them at full capacity: the average machine is used by a firm for only about 9 hours per week on the core product, and 21 hours per week across *all* products. Average weekly employee hours are close to 60, and so this shows the average firm uses machines for only about one third of the time that the firm is open. These results uncover the presence of economies of scale driven by the indivisibility of capital inputs (machines) that increase productivity, but are expensive and have too high capacity relative to the scale of operations of the typical firm.

The fact that firms are small, but productive machines are large and expensive is consistent with two more empirical observations. First, there are low rates of investment in machines (Figure 2). For instance, the thickness planer is owned by less than 10% of producers. Aggregating across machines, Panel (a) of Figure 3 reports the CDF of the "investment rate" defined similarly to the mechanization rate, but considering the share of machines that are *owned* by the firm: about 40% of door producers own *none* of the machines needed in production.

Figure 2: Usage of machines by ownership vs. rental



Notes: Sample: door producers. Share of firms that use each pre-specified machine by whether they own it or rent it, together with average machine prices. The top and bottom 1% of machine prices are trimmed. Conversion rate: 1 USD = 3800 UGX.

Second, firms operating at relatively larger scale are more likely to invest. In Table 3, columns 1 and 2, we regress the investment rate on two proxies for the scale of the firm. The first is the index of managerial ability. This is our preferred measure of firm scale as it captures the production potential of the firm, in line with classic entrepreneurship models where the ability of the manager determines the scale of the firm (e.g., Lucas (1978); Buera et al. (2011b)). The second is the number of workers. This is a standard way of measuring

firm size. However, as capital and labor are (imperfectly) substitutable, firms that operate at sufficient scale to invest in machines might partly substitute labor for capital, thus attenuating the correlation between number of workers and investment. With this caveat in mind, we report results using both measures of firm scale. The table shows a strong correlation between firm scale and investment, regardless of which way we measure it.

Table 3: The role of firm scale for investment and mechanization

	Investment Rate		Mechanization Rate		Share of Machine Hours Rented In	
	(1)	(2)	(3)	(4)	(5)	(6)
Manager Ability (Std.)	0.048		0.025		-0.122	
	(0.011)		(0.011)		(0.023)	
Log Num Workers		0.069		0.043		-0.110
		(0.018)		(0.021)		(0.042)
Mean of Dep. Var.	0.139	0.139	0.381	0.381	0.645	0.645
Sub-county FE	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.200	0.188	0.465	0.466	0.261	0.199
Observations	381	381	381	381	303	303

Notes: OLS regression coefficients, robust standard errors in parentheses. Sample: door producers (columns 1-4) and door producers using at least a machine (columns 5-6). Investment (mechanization) rate: share of pre-specified machine types for the production of core product that are owned (used) by the firm. To compute all outcomes, each machine type is weighted using the share of total machine time it accounts for in the data. Managerial ability: standardized index based on multiple survey questions; see the Supplemental Appendix for details.

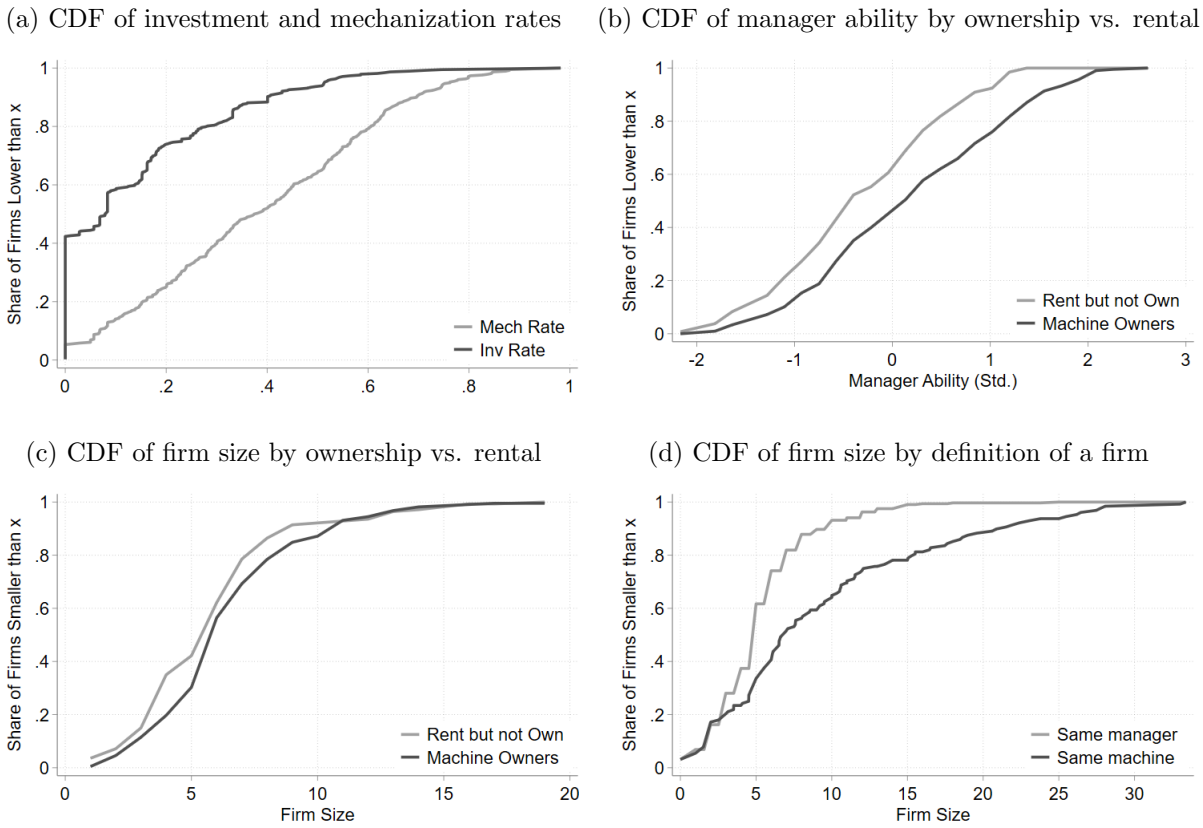
Fact 3: Rental Markets for Machines Help Overcome the Indivisibility

As lack of scale creates a barrier to investment, this raises the potential concern that economies of scale might go underexploited in this economy, hindering mechanization and productivity. However, we discussed that firms operate in large informal clusters, and they produce similar products using similar production steps. Therefore, firms operating at small scale may be able to share the capacity of large machines. A natural market solution would be to organize a rental market for machines. Using our machine-level data, we show that a rental market has indeed emerged, and that this helps small firms overcome the indivisibility.

Prevalence of rental markets. Figure 2 shows that while investment rates are low, renting machines is common. For instance, while less than 10% of firms own a thickness planer, over 50% rent one. Aggregating across machines, Panel C of Table 1 shows that close to two thirds of the machines used by the average door produced are *rented*. Another way to appreciate the extent of the rental market is to compare the CDF of the investment and mechanization rates.

We do so in Panel (a) of Figure 3. The contrast is striking: while over 40% of door producers do not own any of the machines needed for door production, only less than 10% do not use any such machines, and the difference is completely explained by the rental market.

Figure 3: Mechanization, firm scale, and rental markets



Notes: Sample: door producers. Panel (a): CDF of investment and mechanization rate (see Table 3 for definitions). Panel (b): CDF of standardized manager ability by whether the firm: (i) owns at least a machine; (ii) does not own machines but rents at least one. Panel (c): CDF of number of workers by whether the firm: (i) owns at least a machine; (ii) does not own machines but rents at least one. Panel (d): CDF of number of workers according to two definitions: (i) a firm is a set of workers under the supervision of one manager; (ii) a firm is a set of workers using the same machines. To compute (ii), we follow the procedure described in footnote 13. Firm size is trimmed at the top 1% in panels (c) and (d).

The rental market operates primarily between carpenters in the same cluster, with machine owners renting out part of their machine time to other firms. This is possible because machine owners have substantial excess capacity: the average owner uses a machine for 23.9 hours per week, and rents out 10.8 hours of spare machine time to the market.[11] Although other carpentry

[11]The rental market is between firms that are potentially in competition with each other. Since an active rental market exists, any loss of revenues for machine owners from the increased productivity of surrounding firms must be more than offset by the profits from renting out their machines. The limited ability of firms to expand in the output market, documented in the previous section, can explain the sustainability of this arrangement, by creating strong decreasing returns and limiting market stealing.

firms are the primary sources of rentals, about 40% of carpenters report renting from specialized rental workshops. We return to this point in the model, where we explicitly model specialized workshops. The Online Appendix further shows that revenues from the rental market are significant, in line with the cost of capital being high in this economy, something that we verify directly and come back to later.

Rental markets allow smaller firms to mechanize. Consistent with the fact that the rental market helps small firms overcome the indivisibility, we find that the rental market is particularly important for firms operating at relatively low scale. Figure 3, panels (b) and (c), show that machine renters operate at a smaller scale than machine owners. This is true for both proxies of firm scale, although the difference is more pronounced for managerial ability (that is our preferred measure of firm scale): firms that own at least one machine have a managerial ability 0.46 standard deviations higher than machine renters, while they have about 5% more employees. In line with this, columns 5 and 6 of Table 3 show that, conditional on using machines, firms operating at smaller scale rent a higher share of the machine hours they use. Hence, firms that operate at an insufficient scale to buy machines manage to mechanize through the rental market. As a result, Table 3 shows that the correlation between firm scale and mechanization (columns 3 and 4) is weaker than the correlation between firm scale and investment (columns 1 and 2).

Achieving scale collectively? Another way to summarize empirically the prevalence of the rental market and how it allows firms to overcome the indivisibility is to show its implications for the firm size distribution. Firm size is typically measured by the number of workers under the supervision of the firm manager. However, a classic literature in organizational economics views the firm as being defined by the ownership of production assets (Grossman and Hart, 1986; Hart and Moore, 1990). As firms are deeply intertwined through a rental market for machines, redefining the firm boundary as the workers utilizing the same production machines – as suggested by this literature – may be an insightful way to summarize the extent to which the rental market helps firms achieve scale collectively.

We thus compare how the firm size distribution changes as we redefine the boundary of the firm. Specifically, Panel (d) of Figure 3 reports: (i) the size distribution when a firm is defined by the number of employees under one manager, and (ii) the size distribution when a firm is defined by all employees operating the same machines, which we create by reassigning the employees of machine renters to machine owners.[12] The results are striking: once we account

[12]To compute (ii), we identify firms that only rent machines, and we reassign their labor to machine owners as follows: all the workers of each machine renter are first reassigned to the machine types they rent, proportionally to the time that they use each machine type. We then sum across renters to create a "pool" of workers to be redistributed to machine owners for each machine type. We exclude from this pool those workers using machines

for rental market interactions, the average firm size increases by 77%, from 5 to 8.8 employees, and the share of firms with more than 10 employees increases from 5% to 33%. This is especially notable, given that in developing countries firm size distributions based on the typical definition are known to be characterized by a large mass of small firms, with "missing" medium and large firms (Hsieh and Olken, 2014).

This exercise implicitly assumes that all workers that share the same machines face the same cost of using them, regardless of ownership – that is, it assumes that the internal and external cost of capital of the firm is the same. The extent to which this is the case – and so the extent to which small firms achieve scale collectively – however depends crucially on how well the rental market works. We turn to this in the next section.[13]

3.3 Transaction Costs in the Rental Market for Machines

In the previous section, we have shown that through the rental market, small firms are able to access expensive machines. We now estimate the size of transaction costs in the rental market. Transaction costs provide a summary statistic of how well the rental market works, and will play a key role in the quantification of the aggregate benefits of the rental market in the model. We provide two alternative approaches to estimate transaction costs. First, we use our detailed survey to measure those components of transaction costs that are directly observable, such as travel time. Second, we present evidence consistent with a high degree of competition in the rental market, and then build on this to propose a revealed preference approach to identify and estimate the overall size of transaction costs in a manner consistent with our model. This second approach yields our preferred estimate of transaction costs, which we show is nonetheless well aligned with the direct measure from the first approach.

Rental markets operate subject to transaction costs. As most machines are heavy, the rental market is operationalized by workers carrying intermediate inputs to the firm where the machine is located and paying the machine owner a fee upfront to use their machine. Our survey allows us to directly measure those components of transaction costs related to transportation and time costs for machine access. To give a sense of these costs, the average renter visits machine owners 16 times per month, and every time they go they spend 50 minutes traveling,

rented from specialized workshops. Finally, for each machine type, we divide this pool of labor equally among all machine owners, and report the CDF of machine owners as the dark solid line in Panel (d). We only consider machines worth on average at least two months of profits for this exercise.

[13]Finally, we note that it remains a puzzle why more profitable firms do not formally take over smaller and less productive firms, and instead engage in rental relationships with them. There could be many constraints leading to this, such as contracting frictions or a limited span of control (Bloom et al., 2010; Akcigit et al., 2021). While our survey (and our model) is not designed to answer these important questions, we note that through the rental market, firms *de facto* already exploit at least some of the productivity benefits of consolidation, which substantially limits the impact of any such constraints on productive efficiency.

and about one and a half hours waiting for machine access. Wait times can in part be explained by congestion, as almost a third of renters report visiting machine owners in the early morning. To quantify these transaction costs, we compute for each renter: (i) their monthly value of time spent traveling to the machine owners' premises and waiting for machine access; (ii) their direct monthly transportation costs. Comparing the sum of (i) and (ii) with the monthly expenditures on machine rentals shows that transportation and time costs represent about 24% of direct expenditures on rentals, thus revealing that these components of transaction costs are significant. More details on our computation of transaction costs related to transportation and time costs can be found in the Online Appendix.

There may be other transaction costs that we are not able to measure directly in our data (e.g., the risk of missing a sale if customers visit while the manager is at the premises of machine owners). This motivates us to adopt a revealed preference approach to estimate the overall size of transaction costs, which exploits the fact that, as we show next, the rental market seems to be competitive.

Competition in the rental market. The rental market is characterized by spot transactions, so contractual frictions (e.g., Macchiavello (2018); Startz (2019)) are unlikely to be a major concern. We provide five pieces of evidence which suggest that the rental market operates competitively: (i) in each sub-county there are typically a number of machine owners of each type of machine, which likely creates competition and limits monopoly power; (ii) there is no correlation between rental prices and the number of machine owners in the sub-county, while we would have expected a negative relationship if machine owners had market power; (iii) larger machines do not generate higher revenues relative to their cost, which suggests that market power among owners of expensive machines is limited; (iv) when asked how they set rental prices, the majority of machine owners report taking into account the prices of other owners in the area; (v) firms do not report lack of information on who owns machines or the quality/reliability of rented machines as a problem, thus showing that information frictions in the rental market are limited. While this evidence is descriptive, it supports the conclusion that rental markets operate competitively. In the Online Appendix, we provide more details on our evidence that the rental market operates subject to transaction costs but is competitive.

Estimating the size of rental market transaction costs. We quantify the size of the overall transaction costs by studying how these distort the utilization of machine hours by renters. Transaction costs increase the effective price paid by renters for machine access. We assume that the rental price of one hour of machine time p_r is set competitively, but that each transaction is subject to an additional proportional cost τ. The marginal cost of capital for renters is then $p_r(1+\tau)$. For a machine owner instead, the marginal cost of capital is p_r. This is

because, conditional on owning a machine, the opportunity cost of using the machine one extra hour (i.e., the marginal cost) is the price that the firm can earn by renting that hour out to the market.[14] In a standard cost-minimization problem, the firm sets the ratio of the marginal products of capital and labor equal to the ratio of marginal costs. Since machine renters face a higher marginal cost of capital than machine owners, they will have a lower capital-labor expenditure ratio, as long as τ is positive. That is, when compared to owners, renters will use relatively more labor and less capital to perform the same task, as capital is more expensive for them on the margin.

Following this logic, we estimate transaction costs focusing on production steps – that are clearly defined tasks in our case – and regress a step-level measure of the capital-labor expenditure ratio on the share of capital in that step that is rented. Specifically, we create a dataset where each observation is a production step s in a firm j in sub-county c, and run the following regression on the pooled sample of firms and production steps:

$$\log\left(\frac{\bar{p}_{sc}K_{sj}}{\bar{w}_j L_{sj}}\right) = \beta_0 + \beta_1 Rent_{sj} + \vartheta_s + \lambda_c + \delta X_j + \epsilon_{sjc}. \tag{1}$$

The left hand side is the capital-labor expenditure ratio: K_{sj} is the total monthly machine hours used by firm j in production step s; $\bar{p}_{sc}$ is the average rental price for step s faced by firms in sub-county c; L_{sj} is the monthly labor hours used by firm j in step s; and $\bar{w}_j$ is the predicted average hourly wage at firm j. $Rent_{sj}$ is the share of the machines used by firm j in step s that are rented, and so is our key variable of interest.[15] A negative β_1 would mean that steps where machines are rented (as opposed to owned) use relatively more labor, which would then indicate the presence of transaction costs. We include step fixed effects ϑ_s (e.g., dummies for planing, thicknessing etc.) since we pool the estimation across steps. As identification of β_1 requires that renters and owners face the same direct rental cost, we include sub-county fixed effects λ_c, so that we compare firms in the same local rental market. Note that once we include sub-county and step fixed effects, the price level $\bar{p}_{sc}$ is subsumed in these fixed effects.[16] Finally, X_j are firm-level controls. Standard errors are clustered at the firm level.

The main concern with the identification of β_1 are omitted firm characteristics correlated with both the capital-labor ratio and the propensity to rent machines. To address this, we include firm fixed effects in our preferred specification. This allows us to compare the utilization of rented and owned machines across steps *within* the same firm, thus perfectly controlling for

[14] While this is a general insight – that the opportunity cost depends on the market valuation of a good – our interpretation of τ as a pure transaction cost depends on the assumption of competitive rental markets.

[15] In the Supplemental Appendix, we describe how we assign machines to steps and how we aggregate them to create K_{sj}. In creating the shares of rented machines $Rent_{sj}$, each machine type in each step is weighted by the share of total machine hours in the step accounted for by that machine type in the data, so that machines used more intensively in a given step get a higher weight for that step.

[16] This is true as long as the step fixed effects are constant across sub-counties, i.e., $\bar{p}_{sc} = \bar{p}_s \times \bar{p}_c$. Our results are robust to the inclusion of a full set of step by sub-county fixed effects (not reported).

unobserved firm and product characteristics. This approach exploits variation coming from firms that partly own and partly rent machines across different steps. The share of such firms in our data is 44%. As an alternative, we show robustness to controlling for firm-level controls X_j.

Table 4 reports estimates of β_1 from equation 1. Column 1 reports our preferred specification with firm fixed effects. The estimate of β_1 is -0.358, with 95% confidence interval [-0.088 ; -0.628]. β_1 is directly related to the magnitude of transaction costs τ as follows: $\beta_1 = -\log(1+\tau)$. This implies an estimate of $\tau = e^{0.358} - 1 = 0.430$, which means that in steps where machines are rented, the capital-labor ratio is 43% lower. In columns 2 and 3 we show that our estimates are robust to excluding firm fixed effects, and adding firm controls instead: column 2 only controls for step fixed effects, and in column 3 we add our full set of controls. Finally, in column 4 we exclude those machine owners who do not rent out at least some of their machine time, since p_r is a better measure of the marginal cost of capital for those machine owners who engage in the rental market. Reassuringly, our results are unaffected by this sample restriction.

Table 4: Estimates of transaction costs in the rental market

Dependent variable: Log Capital-Labor Expenditure Ratio

	Firm FE	Step FE Only	Firm Controls	Exclude Non-Renters
	(1)	(2)	(3)	(4)
Share of Rented Machines (0-1)	-0.358	-0.279	-0.226	-0.357
	(0.138)	(0.123)	(0.109)	(0.165)
Sub-county FE	No	No	Yes	No
Step FE	Yes	Yes	Yes	Yes
Firm Controls	No	No	Yes	No
Firm FE	Yes	No	No	Yes
Adjusted R^2	0.484	0.046	0.219	0.474
Observations	1,137	1,137	1,137	940

Notes: OLS regression coefficients, standard errors clustered at the firm level in parentheses. Sample: door producers. Level of observation: production steps. Firm controls: managerial ability and dummies for types of doors produced. The numerator of the capital-labor ratio is the total monthly machine hours used by firm j in production step s. The denominator is the total monthly labor hours used by firm j in production step s, multiplied by the within firm predicted hourly wage from a regression of worker wages on firm size and individual worker characteristics. We restrict attention to the seven most common steps out of the pre-specified ten steps for the production of doors, that is steps 3-9. All specifications control for the number of machines used in each production step. The capital-labor ratios are trimmed at the 1st and 99th percentiles. See the Supplemental Appendix for more details on: (i) how we assign machines to steps and how we aggregate machines within step; (ii) the specific production steps corresponding to steps 3-9.

Our estimate of τ is robust to a number of additional specification checks reported in the Online Appendix. In particular, we check robustness to: (i) estimating a more flexible speci-

fication that includes capital utilization (rather than the capital-labor ratio) on the left hand side, and controls for labor utilization on the right hand side; (ii) running a version of equation 1 at the machine level rather than aggregating machines at the step level.

Our results indicate that the overall rental market transaction costs τ are approximately 40% of the direct machine rental price. This shows that while transaction costs are significant, they are not prohibitively large. Comparing this estimate to the direct measure of transaction costs from our survey discussed above shows that transportation and time costs can account for about 60% of the overall estimated transaction costs. This reassures us about the validity of our estimate of τ. Finally, as shown in the Online Appendix, our estimates of β_1 from equation 1 are lower (in absolute value) in sub-counties with higher firm density, while the scale of the firm is not a significant source of heterogeneity. This further confirms that our estimates of τ primarily capture transaction costs related to the time and physical costs of travel, as we would expect these to be smaller in areas with higher firm density, while firm scale should not matter for the size of these transaction costs. As discussed in more detail in the next section, our model will deliver the transaction costs τ as a structural parameter.

4 Model

We develop a model to: (i) quantify the aggregate effects of the rental market on mechanization and productivity; (ii) discuss the mechanisms driving the aggregate gains; and (iii) conduct policy experiments. The assumptions implicit in the model's design are motivated by the empirical results and find support in the data, as we discuss in Section 5.4.

4.1 Setup

We consider a one-period economy, inhabited by a continuum of agents.

Agents. The economy is inhabited by workers and carpentry managers. Workers are homogeneous, have an exogenous yearly income equal to Ψ, which they use to finance consumption, and supply (some of) their labor to the carpentry sector. Carpentry managers, in mass 1, are heterogeneous and each identified by a unique index $\omega \in \Omega$. They differ along two dimensions: (i) the shadow cost of capital, $x(\omega)$, which captures the fact that some individuals might have more assets for self-financing and/or easier access to credit; (ii) a skill term, $z(\omega)$, which determines the manager's productivity. We omit the index ω when not strictly necessary. The cost of capital and managerial skills are jointly distributed with density $g(x, z)$.

Preferences. Individuals consume a general consumption good Y, and a composite carpentry good Y_C, which aggregates the quantities produced by each manager ω, $y(\omega)$. Defining $\hat{\Omega} \subseteq \Omega$

to be the set of active managers producing positive output, the utility function is

$$\begin{aligned} U(Y, Y_C) &= \left[(1-\lambda) Y^{1-\iota} + \lambda Y_C^{1-\iota}\right]^{\frac{1}{1-\iota}} \\ Y_C &= \left[\int_{\omega \in \hat{\Omega}} y(\omega)^{1-\eta} d\omega\right]^{\frac{1}{1-\eta}}, \end{aligned}$$

where $\frac{1}{\iota}$ and $\frac{1}{\eta}$ are the two elasticities of substitution.

The consumers' problem. The representative household chooses how much to consume of each good to maximize utility subject to the budget constraint

$$\begin{aligned} &\max_{\{y(\omega)\}_{\omega \in \hat{\Omega}}, Y} \left[(1-\lambda) Y^{1-\iota} + \lambda Y_C^{1-\iota}\right]^{\frac{1}{1-\iota}} \\ \text{s.t.} \quad &\int_{\omega \in \Omega} p(\omega) y(\omega) d\omega + Y \leq \Psi \end{aligned} \tag{2}$$

where the outside good Y is the numeraire. The assumption of CES demand, see Melitz (2003), implies that the price of the variety produced by manager ω is

$$p(\omega) = \left(\frac{\lambda}{1-\lambda}\right) \left(\frac{y(\omega)}{Y_C}\right)^{-\eta} \left(\frac{Y_C}{Y}\right)^{-\iota}.$$

We define $P \equiv \left(\frac{\lambda}{1-\lambda}\right) Y_C^{\eta-\iota} Y^{\iota}$ so that each manager ω faces a price schedule decreasing in its own output, given by $p(\omega) = y(\omega)^{-\eta} P$.

Production function. Each manager ω has access to two production processes to make the good $y(\omega)$: a non-mechanized one, which uses only labor, and a mechanized one, which uses a combination of labor and capital. If the firm uses the non-mechanized process, output is produced according to

$$y(\omega) = z(\omega) A_L L(\omega)$$

where L is labor, and A_L is a productivity term for the non-mechanized process, identical for all managers. If the firm uses the mechanized process, output is produced according to

$$y(\omega) = z(\omega) A_M K(\omega)^{\alpha} L(\omega)^{1-\alpha}$$

where K is capital, A_M is productivity specific to the mechanized process, and α is the capital share in production.

The outside good Y is in fixed supply.

Machines and capital market. Capital is supplied by machines. There is only one type of machine in the market, which should be interpreted as an aggregate of the different machines

documented in the previous section. Machines can be purchased at an exogenous price p_b (they are supplied elastically), depreciate at rate δ, and have a convex operating cost given by $\chi(C) = \frac{\chi}{1+\xi} C^{1+\xi}$, where $C \leq 1$ is the machine capacity utilization. Machines are indivisible and each firm can purchase either one or zero machines.

Rental market for machines. A manager ω that purchases a machine, chooses to operate it at capacity $C(\omega)$, and uses $K(\omega)$ units of capital in production, has *excess capacity* equal to $C(\omega) - K(\omega)$. Excess capacity is rented out to other firms in a competitive rental market at equilibrium price p_r. The market is subject to a transaction cost τ, or rental market wedge, that renters have to pay for each unit of machine time. The total effective price paid by a renter to use one unit of machine time is $(1+\tau) p_r$, while the machine owner receives the price p_r. The wedge τ captures the transaction costs documented in Section 3.3, such as transportation and time costs to use the rental market. All costs are expressed in units of output.

Labor market. Labor is hired in a partial equilibrium market subject to a convex cost of labor: manager ω hiring labor $L(\omega)$ faces total labor cost equal to $WL(\omega)^{1+\nu}$ where W is the wage level and $\nu \geq 0$. The parameter ν can be interpreted as a reduced form representation of the extent of labor market frictions. If $\nu = 0$, each manager can hire as much labor as she wishes at the equilibrium wage. Instead, if ν is positive, the manager faces an increasing labor supply curve and needs to pay a higher wage to grow the firm size. As a result, there is wage dispersion across firms, and a size-wage premium – as in frictional labor models such as Burdett and Mortensen (1998).

The managers' problem. First, given her managerial ability z, but before observing her cost of capital x, each manager ω decides whether to enter the market and start producing or take an exogenous outside value $\pi_N(z)$. The ex-ante profits for a manager ω are thus given by

$$\Pi(z(\omega)) = \max\left\{ \underbrace{\pi_N(z(\omega))}_{\text{Outside Option}} ; E_x \underbrace{[\pi(x(\omega), z(\omega)) | z(\omega)]}_{\text{Production Profits}} \right\}, \tag{3}$$

where $\pi(x, z)$ is the profit of a manager with traits (x, z). $E_x[\cdot]$ is the expectation taken with respect to the distribution of the random variable x conditional on the managerial ability z. We use this notation throughout the model. The expected profits do not depend on the identity of the manager, or her name ω, but only on her characteristics (x, z). Therefore, we omit ω below. We define a dummy $\mathbb{I}_E(\omega)$ equal to 1 if manager ω decides to enter the market. The set of active managers is then $\hat{\Omega} \equiv \{\omega \in \Omega \text{ s.t. } \mathbb{I}_E(\omega) = 1\}$.

If the manager enters the market, she observes her cost of capital x and then chooses labor, capital, and machine capacity to maximize her profits. She thus solves

$$\pi(x,z) = \max_{L\geq 0, K\geq 0, C\in[0,1]} \underbrace{y^{1-\eta}P}_{\text{Revenues}} - \underbrace{WL(\omega)^{1+\nu}}_{\text{Labor Cost}} - \underbrace{(1-\mathbb{I}_C)}_{\text{Renters}} \times \underbrace{[p_r(1+\tau)K]}_{\text{Capital Cost for Renters}} \tag{4}$$

$$+ \underbrace{\mathbb{I}_C}_{\text{Owners}} \times \left[\underbrace{p_r \max\{0, C-K\}}_{\text{Revenues from Renting Out}} - \underbrace{\frac{\chi}{1+\xi}C^{1+\xi} - (x+\delta)p_b - p_r(1+\tau)\max\{0, K-C\}}_{\text{Capital Cost for Owners}} \right]$$

s.t

$$y = \begin{cases} zA_L L & \text{if } \mathbb{I}_K = 0 \quad \text{[Non-Mechanized Production Process]} \\ zA_M K^{\alpha} L^{1-\alpha} & \text{if } \mathbb{I}_K = 1 \quad \text{[Mechanized Production Process]} \end{cases},$$

where $\mathbb{I}_C$ and $\mathbb{I}_K$ are dummies equal to 1 if the manager chooses to buy the production machine, and to use capital in production, respectively. The max operators within the revenues from renting out and cost of capital for machine owners allow for the possibility that excess capacity is negative, that is, that some machine owners also rent in capital from the rental market.

Definition of the competitive equilibrium. *The competitive equilibrium is given by a vector of entry choice, capital, labor, capacity, output, and output price for each manager ω, $\{\mathbb{I}_E(\omega), K(\omega), L(\omega), C(\omega), y(\omega), p(\omega)\}_{\omega\in\Omega}$, the rental price for machines p_r, and the aggregate price level P, such that:*

1. *the rental market clears: $\int_{\omega\in\hat{\Omega}} C(\omega)\,d\omega = \int_{\omega\in\hat{\Omega}} K(\omega)\,d\omega$;*
2. *the goods' markets clear: $Y_C = \left[\int_{\omega\in\hat{\Omega}} y(\omega)^{1-\eta}\,d\omega\right]^{\frac{1}{1-\eta}}$;*
3. *each potential manager maximizes profits – i.e., solves problems (3) and (4);*
4. *the representative consumer maximizes utility – i.e., solves problem (2).*

4.2 Characterization

We study the role of the rental market in shaping economic activity and productivity. The main objects of interest are the managers' choices of whether to mechanize the production process (i.e., use positive capital, $\mathbb{I}_K = 1$) and whether to invest (i.e., purchase the production machines, $\mathbb{I}_C = 1$) and how these depend on the rental market wedge τ. To simplify the analytical characterization, we work under the following empirically motivated assumption, which we will relax in the quantification.[17]

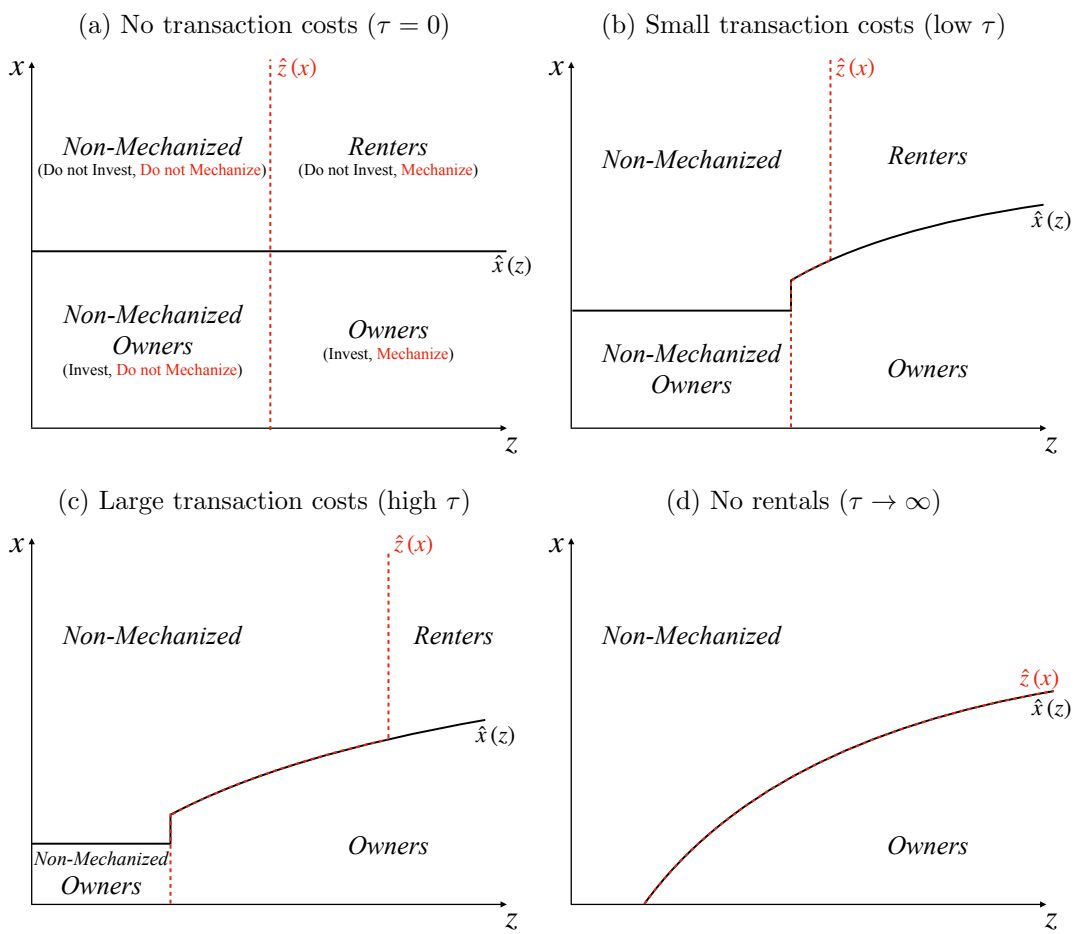
[17] In our data, over 70% of carpenters who own machines also rent out their machines to others.

Assumption 1. *The excess capacity is weakly positive, i.e.,* $C(\omega) \geq K(\omega)$*, for all managers.*

The theoretical results are summarized in the Lemma and Proposition below. Lemma 1 describes the equilibrium structure and how it changes as a function of the rental market wedge τ. Proposition 1 illustrates the aggregate impact of the rental market and the two mechanisms through which it operates.

Lemma 1. *There exist two weakly increasing functions* $\hat{x}(z)$ *and* $\hat{z}(x)$ *such that: (i) managers invest if and only if* $x < \hat{x}(z)$ *and (ii) they mechanize if and only if* $z \geq \hat{z}(x)$*. Furthermore, if* $\tau = 0$*, then* $\hat{x}(z) = \hat{x}$ *for all* z *and* $\hat{z}(x) = \hat{z}$ *for all* x*, while if* $\tau \to \infty$*, then* $\hat{x}(z) = \hat{z}^{-1}(x)$*.*

Figure 4: Equilibrium mechanization and investment choices



Notes: The figure shows the partitions of the (x, z) space into four compact groups of managers: (i) *renters*, that do not invest but mechanize; (ii) *owners*, that invest and mechanize; (iii) *non-mechanized owners*, that invest but do not mechanize and thus rent out all their machine's capacity; and (iv) *non-mechanized* firms, that do not invest nor mechanize. We show these partitions for different values of the rental market wedge τ.

Lemma 1, illustrated in Figure 4, shows that managers are partitioned into four groups with different production choices depending on their ability z and cost of capital x, and that

the shape of the partitioning depends on the rental market wedge τ. When transaction costs are zero (Figure 4a), the choice to mechanize and invest are not related, as mechanization only depends on the return from using capital z, while investment depends only on the cost of capital x. The return from using capital increases in z due to the capital-skill complementarity in the production function. Transaction costs in the rental market instead bundle together capital ownership and utilization (Figures 4b and 4c) as they make capital more expensive to use for renters, and less profitable to rent out for machine owners. This creates misallocation of resources relative to the benchmark without transaction costs. In the extreme case when $\tau \to \infty$ (Figure 4d), mechanization is possible only through investment in machines.

Proposition 1. *For a fixed set of managers $\hat{\Omega}$ and output price P, a decrease in τ yields*

1. Higher profits for all managers: *$\pi(x, z)$ weakly increases for all (x, z).*

2. Higher engagement in the capital market*: the mass of firms that either invest or mechanize, $\int \mathbb{I}_C(\omega)\, d\omega + \int (1 - \mathbb{I}_C(\omega))\, \mathbb{I}_K(\omega)\, d\omega$, increases since the revenues from renting out each unit of machine time – p_r – increase, while the cost of renting in – $(1+\tau)\, p_r$ – decreases;*

3. An improvement in the allocation of capital*: for a constant price p_r, the correlation between mechanization and machine ownership decreases;*

4. An increase in mechanization due to collective scale*: even if we let $x(\omega) = \bar{x}$ for all ω to mute any allocative effects, the average mechanization increases.*

In a well-functioning (low τ) rental market, capital is more valuable, as its equilibrium price p_r increases, but also cheaper to access for renters, as the increase in p_r is not large enough to compensate for the decline in τ. As a result, as long as the aggregate output price P is constant, all managers weakly benefit, irrespective of their production choices (***1.***). Furthermore, the relative returns from both owning and using capital increase, which increases the overall engagement of firms in the capital markets (***2.***).[18]

The overall effects are the result of two distinct mechanisms through which the rental market operates. The first one (***3.***) is akin to a financial market. By unbundling capital ownership and utilization, a well-functioning rental market improves the allocation of capital since managers with the lowest cost of capital (low x) purchase the machine, and the ones with the highest returns from using capital (high z) mechanize. The second one (***4.***) is specific to the rental market and at the core of the idea of achieving scale collectively. In the presence of strong decreasing returns and high-capacity machines, the optimal firm size may not be large enough to justify the investment if the firm must use all the capacity by itself. The rental market allows firms to share the machines' capacity, thus overcoming this problem. The result is that,

[18]Notice that, nonetheless, neither mechanization nor investment must necessarily increase. An improvement in the allocation of capital could decrease overall investment as firms more effectively rely on renting to mechanize. Similarly, mechanization may decrease since when τ is low, the high market value of capital may induce some machine owners to rent out all their capital rather than mechanize.

even when all managers have identical cost of capital $x(\omega) = \bar{x}$, so that the rental market has no allocative role by construction, a well-functioning rental market increases mechanization by allowing more firms to access the same machines. Highlighting and quantifying this second mechanism is a core contribution of this paper.

5 Bringing the Model to the Data

Next, we bring our model to the data. First, we extend the model and parametrize it to make it amenable to a quantitative empirical analysis. Then, we calibrate the parameters that can be computed outside the model and jointly estimate the remaining ones by simulated methods of moments. Finally, we discuss the estimation results.

5.1 Model's Extension and Parametrization

We introduce two extensions: (i) extreme value shocks to smooth out the discrete choice of managers of whether to enter, mechanize, and invest in machines; (ii) an external sector that specializes in renting out machines to capture the fact, shown in Section 3, that a share of the overall market capacity is supplied by specialized workshops.

Extreme value shocks. Each manager ω draws two vectors of preference shocks: (i) $\{\varepsilon_N; \varepsilon_E\}$ where ε_N is for exit, and ε_E for entry; (ii) $\{\varepsilon_m(\omega)\}_{m\in\mathbb{M}}$, where $\mathbb{M}$ is the set of four possible production methods, or the combination of the investment and mechanization choices. The shocks are distributed according to independent Type II Extreme Value Distribution with shape parameters $\tilde{\theta}^{-1}$ and θ^{-1}. Given the realization of the first vector of shocks, the manager decides whether to enter, taking into account the expected value of production which depends on the realization of the second vector of shocks:

$$\Pi(\omega) = \max\{\varepsilon_N(\omega)\pi_N(\omega); \varepsilon_E(\omega)\pi_E(\omega)\}$$

where

$$\pi_E(\omega) = \mathrm{E}_{x,\varepsilon}\left[\max_{m\in\mathbb{M}} \varepsilon_m(\omega)\pi_m(x(\omega), z(\omega))\right]$$

and $\pi_m(x(\omega), z(\omega))$ is the solution to problem (4), imposing as an additional constraint that the manager must follow the production method m.[19]

Frechet-distributed taste shocks smooth out discrete choices and provide analytical expressions for the probability that each option is chosen. The parameter θ modulates the relative roles of shocks and individual characteristics in determining production choices. The higher is

[19]For example, for a renter, $m = \{\mathbb{I}_K = 1; \mathbb{I}_C = 0\}$, we would add to the problem that $K > 0$ and $C = 0$.

θ, the closer the equilibrium resembles the partitions shown in Figure 4. If $\theta \to 0$, all managers are equally likely to adopt any production method, irrespective of their skills and cost of capital.

Specialized rental providers. Specialized machine rental providers, in fixed mass ϕ, do not produce carpentry good themselves, but own machines and rent them out to carpenters, facing the same cost of capacity utilization as carpentry firms. We do not need to take a stand on their interest rate x because they are in fixed supply and their profits are not included in the sector's GDP. Each provider solves the capacity maximization problem

$$\max_{C} p_r C - \frac{\chi}{1+\xi} C^{1+\xi},$$

which yields an additional supply of capital in the market equal to $\phi \chi^{-\frac{1}{\xi}} p_r^{\frac{1}{\xi}}$.

Outside option and heterogeneity. We assume that the outside option of a manager ω is

$$\pi_N(\omega) = \tilde{\pi}_N \left(E_\omega \left[\pi_E(\omega)\right]\right)^{1-\psi} \left(\pi_E(\omega)\right)^{\psi}$$

where $\tilde{\pi}_N$ is a constant term that captures the overall value of the outside option, while ψ captures how sensitive this is to managers' ability. Finally, we assume that the joint distribution of (x, z) is given by two correlated log-normals, yielding five free parameters: $\{\mu_x, \mu_z, \sigma_x, \sigma_z, \rho_{xz}\}$.

Table 5: Economic environment of the model

	Block	Equation	Parameters
(1)	Aggregate Utility	$U(Y, Y_C) = \left[(1-\lambda) Y^{1-\iota} + \lambda Y_C^{1-\iota}\right]^{\frac{1}{1-\iota}}$	ι
(2)	Final Output in Carpentry	$Y_C = \left[\int_{\omega \in \hat{\Omega}} y(\omega)^{1-\eta} d\omega\right]^{\frac{1}{1-\eta}}$,	η
(3)	Heterogeneity: Skills and Int. Rate	$(x, z) \sim g(x, z)$	$\mu_x, \mu_z, \sigma_x, \sigma_z, \rho_{xz}$
(4)	Non-Mechanized Production	$y(\omega) = z(\omega) A_L L(\omega)$	A_L
(5)	Mechanized Production	$y(\omega) = z(\omega) A_M K(\omega)^{\alpha} L(\omega)^{1-\alpha}$	α, A_M
(6)	Cost of Rented Capital	$(1+\tau) p_r K(\omega)$	τ
(7)	Cost of Machine Capacity	$\chi(C) = \frac{\chi}{1+\xi} C^{1+\xi}$	χ, ξ
(8)	Net Cost of Owned Capital	$(\delta + x) p_b + \chi(C) - p_r (C - K)$	δ, p_b, p_r
(9)	Cost of Labor	$W L(\omega)^{1+\nu}$	W, ν
(10)	Capital from Specialized Providers	$\phi \chi^{-\frac{1}{\xi}} p_r^{\frac{1}{\xi}}$	ϕ
(11)	Outside Value of Production	$\tilde{\pi}_N \left(E_\omega \left[\pi_E(\omega)\right]\right)^{1-\psi} \left(\pi_E(\omega)\right)^{\psi}$	$\tilde{\pi}_N$, ψ
(12)	Extreme Value Shocks	$\{\varepsilon_N; \varepsilon_E\}$, $\{\varepsilon_m(\omega)\}_{m \in \mathbb{M}}$	$\tilde{\theta}$, θ

Notes: This table reports all the main building blocks of the quantitative model and highlights the parameters that discipline each block.

Model's summary. Table 5 summarizes the economic environment, including all the building blocks of the model, the main equations that describe them, and the relevant primitive

parameters to be estimated. After we normalize $A_L = 1$, we are left with 22 parameters overall, shown in Table 6. Next, we explain how we pin them down using our data.

Table 6: Model calibrated and estimated parameters

	Parameter	Value	Source		Parameter	Value	Source
(1)	τ	0.430	T.4, c.1	(12)	χ	1.495	
(2)	α	0.50	T.A9, c.4	(13)	ξ	1.157	
(3)	p_b	776.2	T.A10, c.1	(14)	μ_x	1.715	
(4)	p_r	0.514	T.A10, c.1	(15)	σ_x	1.861	
(5)	δ	0.069	T.A10, c.1	(16)	ρ_{xz}	-0.227	
(6)	ι	0.450	BW (2006)	(17)	η	0.078	Jointly Est.
(7)	ϕ	0.976	T.A10, c.1	(18)	ν	0.153	
(8)	A_M	2.447	Jointly Est.	(19)	W	0.291	
(9)	θ	0.659	Jointly Est.	(20)	$\tilde{\pi}_N$	1.611	
(10)	μ_z	-1.012	Jointly Est.	(21)	ψ	0.801	
(11)	σ_z	0.055	Jointly Est.	(22)	$\tilde{\theta}$	2.881	

Notes: This table reports the calibrated and estimated parameters. See the respective source tables and corresponding sections for more details. BW (2006) stands for Broda and Weinstein (2006). The 15 parameters in rows (8) to (22) are jointly estimated using simulated method of moments.

5.2 Calibrated Parameters

We calibrate outside the model the seven parameters that have a direct empirical counterpart.

The rental market wedge τ can be estimated examining the relative capital intensity of machine owners and renters. In fact, the model yields the exact same empirical specification run in Section 3.3 since the following relationship holds for all managers that mechanize

$$\log\left(\frac{p_r K(\omega)}{w(\omega) L(\omega)}\right) = \gamma_0 - (1 - \mathbb{I}_C(\omega)) \log(1+\tau). \tag{5}$$

As shown in Section 3.3, our preferred estimate of transaction costs yields $\tau = 0.43$.

Due to the Cobb-Douglas production, the capital share α is pinned down by the ratio of the capital and labor expenditures, which we compute in the data for each mechanized step. We focus on machine owners since their marginal cost of capital is not affected by the rental market wedge and we find that the capital-labor ratios are very similar across steps. We compute the average, weighted by the share of labor expenditures in each step, and find $\alpha = 0.50$.

We compute the rental and purchase prices, p_r and p_b, directly from our machine-level data, by calculating a weighted average of the reported prices across all the machines in our dataset. The weights are given by the overall number of hours that each type of machine is used in our data. The representative machine costs \$776.2 and is rented at \$0.514 cents per hour.

We compute depreciation δ using, for each machine, the relationship between value and age in our data. We aggregate across machine types using the same weights as for prices and find that the representative machine depreciates at a yearly rate of 6.9%.

Using the same aggregation described above, we calculate the share of total machine capacity supplied from specialized providers. We find that this share is 49.4%, which leads to $\phi = 0.976$ when we normalize the mass of active managers to be equal to 1.

Finally, for the elasticity of substitution for the composite carpentry good, $\frac{1}{\iota}$, we pick 2.2, which is the estimate for "Wood Manufactures, N.E.S." from Broda and Weinstein (2006), who estimate the elasticities of substitution for 3 digit industries using U.S. data. More details on the calibration of each parameter can be found in the Online Appendix.

5.3 Targeted Moments and Identification

We jointly estimate the remaining 15 parameters targeting 38 moments. Table 7 shows all the moments and includes links to the Tables and Figures from which they are taken. Here we discuss how we select the targeted moments and explain how these moments help identify the parameters. In Section 5.4 below, we will describe how we compute each moment in our model to make it as comparable as possible with the data.

Targeted moments. While there is always some degree of arbitrariness in choosing which empirical moments to target, the following rationale guided our choices. Most importantly, we wanted to target *all* the moments corresponding to three facts shown in Section 3.2, as we would like our model to be able to quantitatively replicate these important features of the data. As described below, we also target additional moments, whose computation is described in more detail in the Online Appendix.

The *first fact* is that mechanization is important for productivity. To this end, we target the correlation between revenues and mechanization (with and without controls for managerial ability). These moments, along with their mapping to associated parameters in the model, are shown in rows 18-25 of Table 7. The *second fact* is that scale is a limiting factor to investment in machines since machines have large capacity, while most firms produce little output and thus need to use machines for only a few hours. The *third fact* is that renting is pervasive in our context, helping to overcome the machine indivisibility and increasing overall mechanization relative to investment in machines.

To guarantee that our model is consistent with these last two facts, we target the average mechanization and investment rates, the prevalence of rentals, and their relationship with firm size and managerial ability from Table 3 (shown in rows 1-9 of Table 7). Another implication of these two facts, shown in Figure 3, is that the characteristics of machine owners and renters differ. We target also these moments (rows 10-11). Finally, we ask our model to match the

capacity utilization of machines, and how it differs across owner and renters (rows 12-17). These moments capture the importance of the rental market: if the rental market succeeds in giving access to capital to many firms and in utilizing capital inputs more intensively, we would expect that each firm uses little machine capacity, while each machine is used at high capacity, but by many firms together.

The three facts just described summarize the functioning of the capital market. However, we would like our model to be also broadly consistent with the output, labor, and credit markets, as they affect firm choices and thus modulate the impact of the rental market on the economy. For example, the returns to mechanization depend on the cost of labor. Similarly, the extent to which rentals can improve the allocation of capital depends on how the interest rate varies across entrepreneurs. Therefore, we target several moments that discipline the functioning of these other markets.

For the output market, the average markup is a sufficient summary statistic since we use a CES demand function (row 26). For the labor market, we target the average wage, to match the relative capital and labor costs (row 27). We also target, as useful measures to pin down labor market frictions, the relationship between wages and firm size and the relative capital intensity of high and low ability managers (rows 28-31). In a world with strong labor market frictions, wages increase steeply in firm size, and thus it is expensive to increase output by hiring more workers. For the credit market, we target the average interest rate and its standard deviation, which is a measure of frictions: in a first-best world, all entrepreneurs should have similar cost of capital (rows 32-33).

Finally, we need empirical moments to discipline the outside option of entrepreneurs. This building block of the model is important because it determines the characteristics of the marginal entrepreneurs that enter or exit the sector in the counterfactual exercises of Section 6. We target several moments on the characteristics of managers and how they differ from workers (rows 34-38). We follow this approach since our data suggests that, for most managers, the outside option is to be a worker in the same industry.

Identification. While all parameters are jointly identified, some of them have a stronger effect on allowing the model to match specific moments. To formally explore the connection between parameters and moments, we compute the elasticity of each (model generated) moment to each parameter (as commonly done in the literature, e.g., Kaboski and Townsend, 2011b). The full Jacobian matrix is included in the Online Appendix, but in the last column of Table 7 we report the three most important parameters for each moment from this exercise.[20]

[20] As detailed in the Online Appendix, we include only parameters that play a sufficiently important role for each moment. Specifically, we do not include parameters in the Table if the elasticity of the moment to those parameters is less than what would be implied if all parameters had identical influence on that moment.

Table 7: Targeted moments and model fit

	Moment	Source	Data	Model	Parameters
(1)	Mechanization Rate	T.3, c.3	0.381	0.326	A_M,W,θ
(2)	Investment Rate	T.3, c.1	0.139	0.169	A_M,W,η
(3)	Share of Machine Hours Rented In	T.3, c.5	0.645	0.708	A_M,χ, σ_z
(4)	Mech. Rate on Number of Workers	T.3, c.4	0.043	0.070	A_M,W,η
(5)	Inv. Rate on Number of Workers	T.3, c.2	0.069	0.079	A_M,W,χ
(6)	Share of Mach. Hrs Rented on Num. of Workers	T.3, c.6	-0.110	-0.145	A_M,W, μ_z
(7)	Mech. Rate on Managerial Ability	T.3, c.3	0.025	0.017	η, θ, A_M
(8)	Inv. Rate on Managerial Ability	T.3, c.1	0.048	0.036	A_M, ρ_{xz}, χ
(9)	Share of Mach. Hours Rented on Man. Ability	T.3, c.5	-0.122	-0.051	ρ_{xz}, η, μ_z
(10)	Owners-Renters Managerial Ability Gap	F.3, p.(b)	0.457	0.365	ρ_{xz}, η, μ_z
(11)	Ratio of Size of Machine Owners vs. Renters	F.3, p.(c)	1.057	1.034	A_M,μ_z, η
(12)	Median Hourly Machine Rental Price	T.A10, c.1	0.514	0.514	ξ
(13)	Average Machine-Level Capacity Utilization	T.A10, c.1	0.531	0.585	A_M, χ, W
(14)	Average Firm-Level Capacity Utilization	T.A10, c.1	0.356	0.310	χ, η, μ_z
(15)	Average Firm-Level Cap. Utilization, Owners	T.A10, c.1	0.380	0.415	χ, A_M, θ
(16)	Average Firm-Level Cap. Utilization, Renters	T.A10, c.1	0.338	0.284	χ, η, μ_z
(17)	Average Firm-Level Cap. Rented Out	T.A10, c.1	0.151	0.170	A_M,W ,θ
(18)	Log Revenues on Man. Ability	T.2, c.2	0.288	0.231	σ_z, ν, η
(19)	Log Revenues p.w. on Man. Ability	T.2, c.5	0.144	0.044	η, σ_z ,A_M
(20)	Log Rev. on Man. Ability (and Mech. Rate)	T.2, c.3	0.250	0.226	ν, σ_z, η
(21)	Log Rev. p.w on Man. Ability (and Mech. Rate)	T.2, c.6	0.114	0.031	σ_z, ν, η
(22)	Log Revenues on Mech. Rate	T.2, c.1	1.693	2.421	A_M,σ_z, θ
(23)	Log Revenues p.w. on Mech. Rate	T.2, c.4	1.268	1.076	σ_z,μ_z,θ
(24)	Log Rev. on Mech. Rate (and Man. Ability)	T.2, c.3	1.530	0.249	A_M,W, μ_z
(25)	Log Rev. p.w. on Mech. Rate (and Man. Ability)	T.2, c.6	1.195	0.782	A_M,μ_z,W
(26)	Average Markup	T.A1, c.2	0.229	0.235	ν, η
(27)	Hourly Worker Wage Rate	T.A1, c.2	0.333	0.326	A_M, W
(28)	Log Hourly Wage on Number of Workers	T.A7, c.6	0.146	0.153	ν
(29)	Log Hourly Wage on Managerial Ability	T.A7, c.3	0.060	0.029	σ_z, η,ν,
(30)	Log Capital Used on Managerial Ability	T.A13, c.2	0.398	0.346	η, A_M, σ_z
(31)	Log Labor Used on Managerial Ability	T.A13, c.4	0.135	0.191	ν,σ_z η
(32)	Average Interest Rate	T.A11, c.1	0.329	0.347	A_M, W, μ_x
(33)	Std of Interest Rate	T.A11, c.1	0.281	0.233	A_M, χ, μ_z
(34)	Ratio of Number of Managers to Workers	T.1, c.1	0.222	0.200	$\tilde{\pi}_N$, $\tilde{\theta}$
(35)	Workers-Managers Managerial Ability Gap	T.A14, c.1	-0.285	-0.329	ψ, $\tilde{\theta}$
(36)	Ratio of Std of Income of Workers vs. Managers	T.A15, c.1	0.898	0.804	ψ
(37)	Ratio of Std of Man. Ability of Workers vs. Man.	T.A15, c.1	0.970	0.994	ψ, $\tilde{\theta}$,$\tilde{\pi}_N$
(38)	Entry Choice on Man. Ability (Normalized)	T.A14, c.3	0.275	0.241	ψ, $\tilde{\theta}$,$\tilde{\pi}_N$

Notes: This Table shows all the moments used for the model estimation. For each moment, the second column includes links to the tables (T) and figures (F) where the moment is computed, with corresponding columns (c) and panels (p). The third and fourth columns then show the parameters' values in the data and in the model. Finally, the last column shows the key parameters for each moment from the Jacobian matrix.

To help build intuition, we offer a few comments on the results from the Jacobian. We discuss the parameters in four blocks: (i) $A_M, W, \mu_z, \chi, \theta, \mu_x$ impact, through different margins, the returns to mechanization; (ii) η, ν, ξ determine the extent of decreasing returns to scale in the model; (iii) $\sigma_z, \sigma_x, \rho_{xz}$ modulate the heterogeneity across individuals; (iv) $\tilde{\theta}, \psi, \tilde{\pi}_X$ shape the outside option and thus the composition of active entrepreneurs.

The relative productivity of the mechanized process (A_M) and the wage level (W) can be discussed together, as they have a similar impact on the equilibrium. If A_M and W are high, capital is relatively productive and cheap, inducing managers to both mechanize and invest. These two parameters, and especially A_M, are among the most relevant ones for many of the moments. This is not surprising since the returns to mechanization is a key factor in determining the equilibrium in the market for capital. Also, it is a reassuring result as it suggests that there is not one single moment that is likely to drive the aggregate productivity effect, thus reducing potential concerns about measurement error or omitted variables in the creation of each individual moment – a conjecture that we formally verify using the sensitivity approach of Andrews et al. (2017), as discussed in Section 6. The average ability (μ_z) and the cost of capacity (χ) can also be discussed together since they mainly affect (in different directions) the capacity at which each machine is used: if either capacity is expensive or the typical entrepreneur has low productivity, hence produces little output, then machines are used at low capacity. These parameters tend to be relevant for moments about the capacity utilization (rows 13-17). The variance of the Frechet shocks, modulated by θ, determines the relative role of productivity and taste shocks in driving managers' choices. If θ is low, the mechanization choice is mostly driven by the random taste shocks. Consistent with this, θ is most relevant in determining the relationship between mechanization and managerial ability (row 7). The average cost of capital (μ_x), which affects the cost of purchasing machines, plays a less important role than the previous parameters, but still shows up in the Jacobian matrix where anticipated, on the moments related to the functioning of the credit market (row 32).

As expected, the price elasticity of demand (η) maps directly into the markup (row 26), and the labor market friction parameter (ν) impacts both the markup and all the moments that we selected on purpose to discipline its strength (rows 28-31). In addition, both a high price elasticity of demand (η) and strong labor market frictions (ν) generate decreasing returns to scale, thus limiting the ability of high skilled managers to expand. These parameters are crucial to determine the relationship between firm revenues and managerial ability (rows 18-21). The curvature of the cost of capacity utilization (ξ) is pinned down independently by the rental market clearing at the observed rental price (row 12). The larger is ξ, the higher the profitability of renting out machines, hence the more managers choose to invest.

The larger is the variance of productivity (σ_z), the steeper we would expect the relationship between log revenues and managerial ability to be since σ_z affects the variance of revenues and

not, by construction, the variance of managerial ability, which is always standardized (both in the data and in our model). Therefore, we are not surprised to see σ_z showing up as a key parameter for all the moments related to the relationship between firm revenues and managerial ability (rows 18-21). The correlation between managerial ability and the cost of capital (ρ_{xz}) is crucial to determine how likely high skilled managers are to access capital through the rental market than to own machines (rows 8-10). If ρ_{xz} is negative and large, the probability of investing in machines would increase steeply with managerial ability, due both to larger returns and lower costs. The variance of the cost of capital (σ_x) turns out not to play a major role. Yet, as can be seen in the Jacobian, it is relatively more important, as expected, in determining the standard deviation of the interest rate. The reason why this parameter is not particularly important is that the standard deviation of the interest rate is computed, both in the model and in the data, only among the selected group of entrepreneurs that choose to invest in machines, a choice affected by other parameters as well.

Finally, the average value of the outside option ($\tilde{\pi}_N$), its sensitivity to managers' ability (ψ), and the scale parameter for the distribution of the entry taste shocks ($\tilde{\theta}$), determine the mass and characteristics of individuals that become managers. As expected, the Jacobian matrix shows that they are the key parameters to determine the moments that we selected to discipline the outside option of entrepreneurs (rows 34-38).

5.4 Estimation Results and Discussion

In practice, to estimate the model, we follow the standard indirect inference approach and run the same regressions using both our survey data and the model-generated data. While the approach is straightforward, the model-generated data requires two small intermediate steps before running the empirical specifications. First, we need to smooth out the discrete mechanization and investment choices. In the data, we compute mechanization rates, investment rates and share of machine hours rented in, aggregating across all the used machines, as explained in details in Section 3.2. In the model, each manager makes a discrete choice of whether to mechanize and invest in a machine. To transform the discrete choices into rates, we project all the individual firm outcomes on the distribution of managerial characteristics. For example, the mechanization rate for the type (x, z) would be the share of managers with characteristics (x, z) that choose to mechanize. Second, we need to transform the primitive ability z to make it comparable to our empirical index of managerial ability.[21] In practice, we create a standardized measure of managerial ability, $\log \hat{z}$, which normalizes $\log z$ to have mean 0 and standard deviation 1, and we then use this measure to run the regressions with the model-generated data.[22]

[21] To construct the moments on managers' selection, we use the predicted managerial ability of employees, as our index of managerial ability was collected only for managers. See the Online Appendix for details.

[22] Reassuringly, we find that the (standardized) distribution of the managerial ability index in the raw data follows a distribution close to a normal, which is the one assumed in the model. Notice also that, since the units

We can then simply solve for the set of parameters φ that satisfies $\varphi^* = \arg\min_{\varphi \in \mathbb{F}} \mathcal{L}(\varphi)$, where $\mathcal{L}(\varphi) \equiv \sum_r \left[(m_r(\varphi) - \hat{m}_r)^2 \right]$, $m_r(\varphi)$ is the value of moment r in our model given parameters φ, and $\hat{m}_r$ is the vector of moments computed in the data.

Results. The estimated vector of parameters φ^* is shown in Table 6, while the corresponding model's moments, $m_r(\varphi^*)$, are in Table 7. The model offers a good fit of the data, especially considering that we used 15 parameters to target 38 moments. At the same time, the fit of the model is, as expected, not perfect. Mainly, the model has a hard time to replicate the strong direct effect of mechanization on revenues once we condition on managerial ability. We notice, however, that managerial ability is likely measured with error in the data, hence the large empirical coefficient that we target might be overestimated due to mechanization being correlated with true managerial ability.

Overall, the ability of the model to replicate all the core patterns documented in Section 3.2 on the relationships between scale, mechanization, and the rental market builds confidence in our estimated parameters. We next discuss a few key ones. We find moderate decreasing returns to scale coming from product differentiation ($\eta = 0.078$). The elasticity of substitution across doors is roughly 13, consistent with the fact that we are looking at a narrow sector, where product differentiation is present, but limited.[23] The labor market frictions are almost identical ($\nu = 0.153$) to what would be pinned down from a regression of wage on size, although several other moments help us to identify ν in the estimation. The labor market frictions are sizable: one way to interpret their size is to notice that the markup, which is inversely related to firm size, would decrease by approximately 50% in their absence. We find that the cost of capital is negatively correlated with managers' ability ($\rho_{xz} = -0.227$), consistent with evidence in the literature (see Banerjee (2003)) and from our context, as discussed further in the Online Appendix.

Discussion of model's assumptions. In the next section, we are going to use the estimated model for a quantitative analysis. As usual, our results will hinge on the assumptions made in the model, which we discuss here. Four of them are particularly relevant.

First, our model is static and thus ignores consumption/savings decisions and asset accumulation. This choice is driven by the nature of our data, which is made of one cross-section. Nonetheless, we allow individuals to have different cost of capital x. We estimate the cost of capital to be negatively correlated with managerial ability, which may be capturing, in reduced form, the fact that more successful managers are able to accumulate more capital (Moll, 2014).

of the empirical index of managerial ability are not directly interpretable within the model, we do not directly match the distribution of the empirical index to estimate the distribution of $\log z$, and instead we target the moments described in the previous section and shown in Table 7. See the Supplemental Appendix for details.

[23] In this setting, the parameter η may also capture frictions in the output market.

Since the distribution of x is exogenous, our counterfactuals should be interpreted as keeping the distribution of access to capital constant, while - in practice - it may change in dynamic models, as in Cavalcanti et al. (2021). Our analysis abstracts from this additional feedback effect.

Second, we have assumed that, despite the transaction cost, there is perfect competition in the rental market, while the labor market is frictional and firms have monopsony power. These assumptions are relevant. Perfect competition in the rental market is used to estimate the size of the rental wedge τ in Section 3.3. The frictions in the labor market limit the ability of firms to grow by hiring labor, thus increasing the importance of the rental market for capital, as we further explore quantitatively below. Given the importance of these assumptions, we presented extensive evidence to justify them in Sections 3.1 and 3.3.

Third, firms can only purchase one machine, which prevents the firms with low capital costs from essentially taking over the rental market. This assumption is motivated by our setting, in which we show that less than 7% of firms use more than one machine of each type. However, it also reminds us that the model is intended for a low-income country and should not be used, in its current form, to study countries in which firms produce at large scale and with multiple machines of the same type.

Fourth, we model the labor market in partial equilibrium, as captured by the fixed wage level W. We made this assumption to reflect that we are studying only one sector within Uganda which is unlikely to affect the overall wage level, especially since the training to become a carpentry worker is quite moderate so that an increase in demand for labor would simply lead to reallocation from other sectors.

Finally, we have assumed that mechanization only affects the quantity of output produced, but not its quality. In practice, while of course mechanization also affects product quality, given the CES demand system, distinguishing between productivity and quality is irrelevant.

6 Quantifying the Importance of the Rental Market

We next use the estimated model to study the role of rental markets for economic development. We quantify the aggregate effects in our context, explain the mechanism through which these effects manifest, and draw general lessons for development policy.

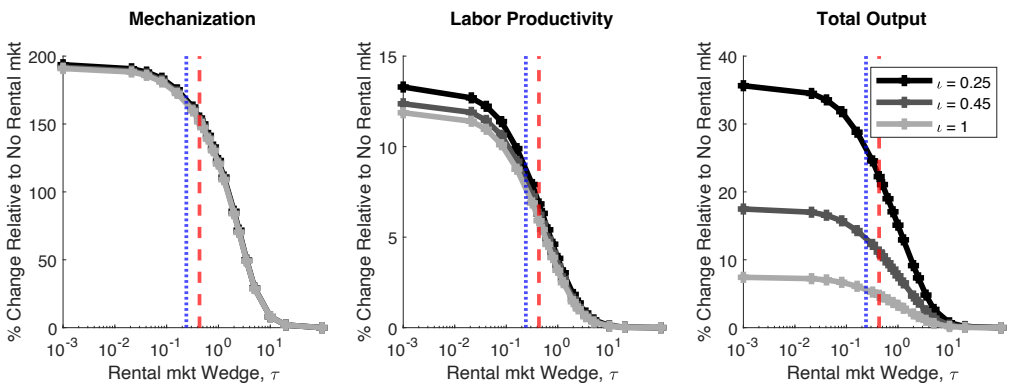
To do so, we rely on model's counterfactuals as we vary the size of the rental market wedge τ. In our context, changing τ shows how the aggregate effects of the rental market on the Ugandan economy depend on the underlying transaction costs. Beyond our context, several other reasons may prevent a rental market from functioning properly, or even from emerging. For example, a market leader might want to leverage its dominant position and not share production machines with a smaller competitor. While the quantitative results hinge on the specific market structure

that we documented in our context – characterized by many small producers facing decreasing returns – the takeaways from this section should speak more broadly about the role of rental markets for development.

6.1 Aggregate Effects of the Rental Market

We calculate the equilibrium of an economy that keeps all primitive parameters constant at their estimated values but varies the rental market wedge (τ). Managers switch their entry decisions and production methods, and the prices of output and rented machines vary to clear the markets. The price to purchase a machine, p_b, is instead kept constant.

Figure 5: Aggregate effects of changing the rental market transaction costs τ



Notes: The figure shows the impact of changing the rental market wedge τ on aggregate outcomes. Each panel shows, for a different statistic of interest, the percentage change relative to an economy without a rental market. The red dotted line highlights the level of the rental market wedge estimated in our data, while the blue dotted line shows the value that we could directly assign to transportation and time costs. We show the results for three values of the elasticity of substitution between aggregate GDP and the composite carpentry good, ι.

Figure 5 shows the results. We consider values of the rental market wedge $\tau \in [0, \bar{\tau}]$, where $\bar{\tau}$ is a value sufficiently large to shut down the rental market. We plot mechanization, labor productivity and total output, normalized relative to an economy with no rental markets. We also consider 1 and 4 as alternative values of $\frac{1}{\iota}$ (2.2. is the benchmark value). To highlight the aggregate gains that could be achieved by reducing the rental market wedge, we plot in red the estimated value of τ from our revealed preference approach, and in blue the value of τ that we could assign to transportation and time costs based on our direct survey evidence described in Section 3.3.

The rental market has large aggregate effects. Transitioning from an economy without a rental market to one with no transaction costs increases aggregate output by 17.5%, average labor productivity by 12.4%, and the share of firms that are mechanized by 192%.[24] Importantly,

[24]The impact of the rental market on aggregate output is mediated by the size of the elasticity of substitution

our benchmark economy with $\tau = 0.430$ achieves *more than half* of the total possible gains. In this sense, the rental market in urban Uganda is a key determinant of aggregate productivity and allows firms to reap a large share of the benefits of scale, or to *achieve scale collectively.*

Why are the aggregate effects so large? The large aggregate effects on productivity, and hence output, are the result of two key elements: (i) an increase in mechanization leads to large productivity gains; (ii) a well-functioning rental market has a large effect on mechanization. We next discuss both.

First, our structural estimates imply a large causal effect of mechanization on productivity: the mechanized production process is more than twice as productive as the non-mechanized one ($A_M = 2.45$). A simple back of the envelope calculation shows that the large increase in mechanization obtained by reducing the rental market wedge from $\bar{\tau}$ to 0 (in this case the mechanization rate increases from 13% to 37% – the $\sim 200\%$ change shown in Figure 5) would lead to an increase of 29% in the unweighted average productivity.[25] The average productivity gain shown in Figure 5 is considerably smaller since, as we explain in details in the next section, the marginal managers that mechanize through the rental market are the relatively low productivity ones, which manage small firms.

Second, we shed light on why the rental market leads to such a large increase in mechanization. The mechanization rate increases due to two margins: more firms purchase machines (the investment rate increases from 13% to 19%) and each machine is used more intensively due to the increase in the equilibrium rental price (capacity utilization increases from 51% to 71%). Given our estimates of the distribution of the cost of capital relative to the returns from investing in machines, a decline in the rental market wedge increases the profits from renting out machines and leads to a sizable (6%) increase in the number of firms that purchase a machine. Most importantly, machine capacity can be effectively diffused through the economy by the rental market, leading to a much larger (24%) increase in the share of firms that mechanize. This magnifying effect of the rental market is due to fact that, both in the data and in the model, machine capacity is much larger than the typical firm's needs. Even the mechanized firms use on average $\sim 30\%$ of the machine's capacity, implying that each machine can be shared by many firms. Overall, the key driver of the large observed gains from the rental market is the mismatch between the large machines' capacity and the small equilibrium firm size, which is generated in the model by the low average managers' productivity and steeply decreasing returns to scale.[26]

$\frac{1}{\iota}$. When ι is large, the scope for the carpentry sector to expand is limited and thus a reduction in τ would lead to a decrease in employment, as firms substitute labor for the relatively cheaper capital.

[25]The unweighted average productivity is given by $0.87 \times A_L + 0.13 \times A_M = 1.19$ when the mechanization rate is 13% ($\tau = \bar{\tau}$), and by $0.63 \times A_L + 0.37 \times A_M = 1.54$ when it is 37% ($\tau = 0$).

[26]In the Supplemental Appendix we use the sensitivity matrix approach of Andrews et al. (2017) to show that the aggregate effects are not mainly driven by just a few empirical moments, suggesting that the quantitative

6.2 How and Why the Rental Market Shapes the Economy

Next, we use the model to zoom into how and why the rental market affects the economy. In Figure 6a, we study how the rental market affects which managers mechanize and invest, focusing on the comparison of the benchmark economy with the two polar cases with $\tau = 0$ (no transaction costs) and $\tau = \bar{\tau}$ (no rental market). Our objective is to illuminate the two core benefits of the rental market described in Proposition 1: (i) to allow more firms to access machines, overcoming the cost of indivisibility through collective scale, and (ii) to improve the allocation of capital by unbundling ownership and utilization. In Figure 6b, instead, we quantify how the prevalence of the rental market in our setting is affected by the large estimated imperfections in other markets. Our goal is to highlight the characteristics of our setting that make rental markets important.

The rental market allows firms to achieve scale collectively. The solid black line with round markers in Figure 6a shows that, as in the data, mechanization increases in managerial ability. Comparing across panels, we notice that: (i) the level of mechanization increases for all managers as we reduce the size of τ; (ii) it increases disproportionally more for the relatively low ability ones. The rental market allows firms, especially the ones operating at lowest scale, to access capital by breaking the indivisible machines into divisible time units, which small firms can afford without having to pay prohibitive fixed costs. At the same time, it also benefits the relatively large firms, due to the fact that, even for them, machine capacity is too large relative to their scale of production: *all firms thus benefit from collective scale.*

The gray line is the share of managers that mechanize accessing machines through the rental market. This relationship is not increasing with managerial ability since, conditional on mechanizing, high skilled managers are more likely to invest, due to both their larger scale and lower cost of capital (recall that we estimate a negative correlation between z and x). Corroborating the discussion above, all managers rely extensively on the rental market to mechanize, especially when τ is low, but relatively low skilled managers do so even more.

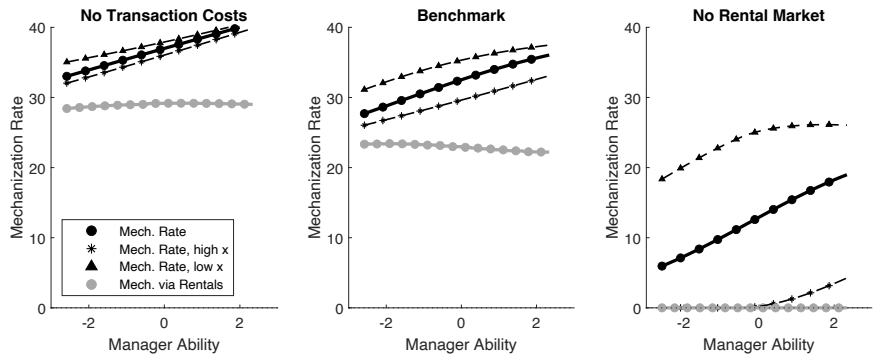
The rental market unbundles capital ownership and utilization. Next, we focus on the average mechanization rates for managers with cost of capital below and above the median. The managers with lower cost of capital are always more likely to mechanize, but the gap in mechanization rate between high and low cost of capital managers increases steeply as a function of τ. By unbundling capital ownership and utilization, the rental market allows access

predictions of the model are fairly robust. Nonetheless, a few moments are particularly relevant. As expected, the aggregate productivity gains are larger the more prevalent is renting and the lower is the machine's capacity utilization of firm owners (i.e., the higher is the excess capacity that can be rented out). Also, they are larger if the income variance of workers and managers is similar, hence if managers are weakly selected: when selection is strong, a decline in τ brings in mainly low productivity managers.

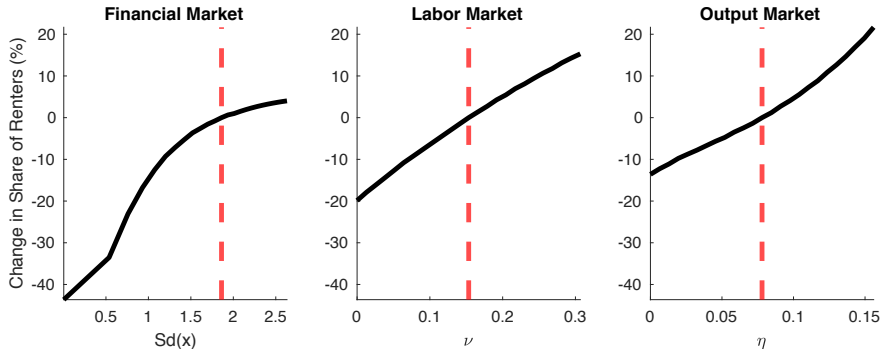
to machines even for managers with a prohibitively high cost of capital, thus effectively working as a substitute for the financial market. Through this channel, the rental market reduces the misallocation induced by the dispersion in the cost of capital.[27]

Figure 6: Understanding how and why the rental market shapes the economy

(a) Impact of the rental market on mechanization, as a function of manager characteristics



(b) Prevalence of rental markets in different economies



Notes: Sub-figure (a) shows the mechanization rate as a function of managerial ability, and separately for managers with cost of capital above or below the median. In gray, we show the share of managers that access machines through rentals. The left panel shows an economy with $\tau = 0$, the middle one the benchmark with $\tau = 0.43$, and the right one the case with $\tau = \bar{\tau}$. Sub-figure (b) shows how the share of managers that rent changes as we vary the imperfections in the financial, labor and output markets, as captured by the dispersion of the cost of capital across managers ($Sd(x)$), the labor market frictions (ν), and the firm-level decreasing returns to scale (η). The red dotted lines highlight each parameter's benchmark in the estimated model.

The rental market attenuates other market imperfections. In Figure 6b, we recompute the model as we vary three parameters that capture the extent of frictions in the financial, labor, and output markets. The left panel shows that the rental market becomes less prevalent as the dispersion of the cost of capital is reduced.[28] The rental market facilitates the reallocation of

[27]The overall average mechanization rate of high skilled managers is closer to the one of managers with below median interest rate. This is due to the estimated negative correlation between z and x. Also, notice that even with no transaction costs managers with low interest rate are slightly more likely to mechanize. This is due to the extreme value shocks. In the limit with $\theta \to 0$ this would not be the case.

[28]While reducing the dispersion of x, we also change its mean to keep constant the average cost of capital of managers that invest.

capital across firms and thus it shrinks if banks can do that task. The middle panel shows that fewer managers need to rely on the rental market if we reduce labor market frictions. Labor market frictions keep firms small, thus preventing them to reach sufficient scale for investing. Lastly, the third panel shows that increasing the elasticity of substitution across managers reduces the mass of renters in equilibrium. When η is large – that is, when the ability of productive firms to expand at the cost of the unproductive ones is limited – many low ability managers enter the market, operate at a small scale, and rely on the rental market to mechanize.

Overall, we learn that the rental market is important in our context because it creates a workaround for other imperfections. These results show that we expect rental markets to become less relevant as countries develop, the average firm size increases, and market imperfections vanish. Using data from the World Bank Enterprise Surveys, we find that the prevalence of rental markets for capital is indeed lower in higher income countries (see the Online Appendix for details).

6.3 Rental Markets Shape the Effectiveness of Development Policies

Finally, we show that taking into account the presence and functioning of the rental market has sharp implications for development policies. Our main exercise uses the model to analyze the effectiveness of different policies aimed at increasing mechanization, and how this depends on the rental market. In doing so, we also highlight the role of general equilibrium effects.

The rental market reduces the benefits of subsidies to purchase machines. We first consider a subsidy to purchase a machine equal to the median monthly profit (136$). This subsidy, which is of similar size to typical capital grants for firms studied in the literature (Banerjee et al., 2019; Janes et al., 2019), translates in our setting to a reduction of 17.5% of the estimated cost of the representative machine.

Row (1) of Table 8 shows the effects of the subsidy comparing the equilibrium outcomes of two economies where rental markets operate as in our baseline economy (i.e., with $\tau = 0.430$) and that are identical in all parameters, but for the fact that in one all firms receive a voucher that decreases the price of the machine. The subsidy increases mechanization, productivity and output. The effects are sizable if compared with the direct cost of the policy: column (4) shows that each dollar spent on subsidies generates $1.24 in increased GDP, or a net benefit of 24 cents on a dollar. Yet, as we next show, the effectiveness of this policy is limited by the presence of the rental market.

In row (2), we compute the effects of an identical policy, but starting from an economy without a rental market. To keep the comparison budget neutral, we adjust the size of the subsidy so that, given the endogenous take-up, the total expenditure in machine vouchers is identical in the two scenarios. We learn that the subsidy is much more effective in the economy

without the rental market, generating *six times* as large effects on mechanization and *three times* the net benefit. Given our estimated parameters, in the absence of a rental market the relatively high price of machines prevents most firms from investing, hence from accessing technology. Thus, the subsidy affects all managers in this case, as investing is the only viable mechanism to access capital when rental markets are not available.

This comparison shows that the effectiveness of subsidies to purchase machines, such as import subsidies for capital equipment, is expected to be larger in economies or sectors were rental markets are less prevalent.

Table 8: Impact of subsidies for buying or renting machines

		$\Delta \mathbb{I}_K$ Mechanization (1)	$\Delta \frac{PY_C}{L}$ Productivity (2)	ΔPY_C Output (3)	$\frac{\Delta PY_C}{Cost}$ Return on 1 \$ (4)	$\Delta E_{\underline{x}}[\pi_N(\omega)]$ Profit, low x (5)	$\Delta E_{\bar{x}}[\pi_N(\omega)]$ Profit, high x (6)
	Subsidies:	*Rental Market and Policy Effectiveness*					
(1)	to buy	+4.98%	+1.4%	+1.44%	1.24 \$	+2.25%	+0.14%
(2)	to buy ($\tau = \bar{\tau}$)	+29.89%	+1.65%	+2.25%	1.74 \$	+3.16%	+2.24%
		Comparing Policies					
(3)	to rent	+4.44%	+1.37%	+1.44%	1.82 \$	+0.88%	+1.71%
(4)	to buy & rent	+4.75%	+1.39%	+1.44%	1.5 \$	+1.5%	+1.01%
		Equilibrium Effects					
(5)	to buy (PE)	+3.54%	+0.8%	-0.72%	-0.62 \$	+3.27%	+0.31%
(6)	to rent (PE)	+15.25%	+4.69%	+2.77%	3.5 \$	+6.99%	+13.48%

Notes: Each cell shows the percentage difference relative to the benchmark economy. Each column corresponds to a different aggregate statistic, while each row to a different policy counterfactual, as described in the text.

Rental vouchers can improve the equity of subsidies. We next consider rental vouchers, along the lines of the policy studied in the agricultural context by Caunedo and Kala (2021). We consider vouchers that reduce the price paid by renters for each unit of capital and solve for the amount that provides the same overall increase in GDP as the purchase subsidies considered above, which turns out to be 15.5%. The two policies provide, by construction, identical aggregate effects.[29] However, they have very different distributional consequences. The purchase subsidy increases mainly the profits of managers with low cost of capital (row (1), columns 5 and 6) since few of those with a high cost of capital invest even with the subsidy. High cost of capital managers are mostly affected through the general equilibrium effects, that is, through

[29]The two policies have different costs. However, the two are not directly comparable since the purchase subsidy increases the overall *stock* of capital in the economy, thus having longer lasting effects. To compare the two, we compute the internal rate of return, taking into account depreciation, that would generate the same return on a dollar for the two policies over one year. We find this rate to be 61.2%, showing that rental subsidies are the most effective alternative only if the opportunity cost of capital is large enough.

the reduction in the rental price, which favors them, and the reduction in the output price, which hurts them. The rental vouchers, instead, benefit disproportionally those with a high cost of capital, as they are more likely to rent (row (3), columns 5 and 6). Managers that invest still benefit, due to the increased demand for rentals and the resulting hike in the rental price.

Depending on which firms policy-makers wish to help the most, they might prefer to use purchase or rental vouchers, or both. For example, in row (4) we show that a policy that assigns an equal subsidy to purchase and rent can be more equitable, while still achieving by construction the same impact on GDP.

Results from partial equilibrium RCTs could mislead policy-makers. While RCTs can usually identify the impact of policies in partial equilibrium, policy-makers are primarily interested in the impact of policies at scale, hence taking into account general equilibrium effects. Motivated by this observation, we next use our model to study, for our two discussed policies, how the partial equilibrium evidence that could be gathered through an RCT relates to the aggregate results computed with the model.

In rows (5) and (6), we compute the average effects of the two types of subsidies while keeping constant the entry choice, aggregate output and rental prices, thus essentially evaluating the average treatment effects of interventions that target a small number of firms. In order to make the results comparable with rows (1) and (3), we create the aggregate effects by assigning to all firms in the economy the average treatment effects from this hypothetical RCT.

The comparison between the general and partial equilibrium effects differs widely across policies. The rental vouchers (row (6)) have a much larger effect in partial equilibrium since three types of equilibrium effects dampen the aggregate results: the rental subsidy (i) leads marginal, lower ability managers to enter; (ii) increases the price of machines in the rental market; and (iii) decreases the price of output. The opposite, instead, is true for the purchase subsidy (row (5)), which in partial equilibrium would lead to smaller effects on mechanization and productivity, and even to a negative effect on GDP due to managers shifting from production to investing, attracted by the high returns from renting out capital, and reducing their labor and output as a result. In this case, the general equilibrium effects are larger since the reduced rental cost of capital, generated by the increased supply of machines, leads more firms to mechanize and enter the market.

Overall, our results offer a concrete example that highlights the challenge of extrapolating from partial equilibrium reduced form estimates to aggregate predictions on the impact of policies at scale (Bergquist et al., 2019; Egger et al., 2019).

Industrial parks and urban planning. Finally, we notice that the rental market provides an additional, and often overlooked, benefit to industrial parks. While most of the discussion

in the literature concerns the returns from shared infrastructure, such as roads and electricity access (Steenbergen and Javorcik, 2017), our results suggest that industrial parks could also generate large returns from capital pooling, as locating many firms in close proximity to one another is likely to reduce the transaction costs in the rental market.[30] Further, as we have shown that smaller firms are more likely to rent, while larger ones to own machines, our work implies that properly designed industrial parks should include both relatively larger and smaller firms. The former would benefit from accessing customers in the rental market, while the latter from being in close proximity to firms that are more likely to be machine owners.

7 Conclusion

Small firms in developing countries are often organized in large informal clusters. In this paper, we show that this feature of the organization of production limits the costs of small scale by allowing firms to achieve scale collectively: while machines are indivisible, their capacity is divisible and can be shared among firms located near each other.

We combine a novel firm survey in urban Uganda with an equilibrium model of firm behavior. The data provides direct evidence of economies of scale driven by the indivisibility of modern machines, but also reveals that their capacity is traded between small firms in an active rental market. The model allows us to quantify the large aggregate effects of the rental market on technology adoption and productivity, to show that these effects are due to the size of other frictions that keep firms small, and to explain that taking rental markets into account has important implications for the design of development policies.

Our work offers a case study that highlights the importance of the rental market for understanding productivity in one (large) sector in one developing country. While the narrow focus was useful to gain a deep knowledge of the institutional setting and properly measure how firms produce output, our overarching goal is to draw general lessons for economic development. Three takeaways strike us as particularly important. First, rental markets can be a powerful workaround for other market imperfections, thus limiting the aggregate costs of frictions that could keep firms small. Second, to understand technology adoption in low income countries, it is important to take into account firm-to-firm interactions within informal clusters, while focusing on the small scale of firms in isolation might be misleading. Third, in settings with large and indivisible production machines, rental vouchers can be an effective and equitable policy tool to increase overall mechanization and boost productivity.

[30] Corroborating this idea, we show in the Online Appendix that the estimated rental market wedge is smaller in areas with higher firm density.

References

Abebe, Girum, Stefano Caria, Marcel Fafchamps, Paolo Falco, Simon Franklin, and Simon Quinn, "Anonymity or Distance? Job Search and Labor Market Exclusion in a Growing African City," *Review of Economic Studies*, 2020, *forthcoming.*

Akcigit, Ufuk, Harun Alp, and Michael Peters, "Lack of selection and limits to delegation: firm dynamics in developing countries," *American Economic Review*, 2021, *111* (1), 231–275.

Alfonsi, Livia, Oriana Bandiera, Vittorio Bassi, Robin Burgess, Imran Rasul, Mushi Sulaiman, and Anna Vitali, "Tackling Youth Unemployment: Evidence from a Labor Market Experiment in Uganda," *Econometrica*, 2020, *88* (6), 2369–2414.

Andrews, Isaiah, Matthew Gentzkow, and Jesse M Shapiro, "Measuring the sensitivity of parameter estimates to estimation moments," *The Quarterly Journal of Economics*, 2017, *132* (4), 1553–1592.

Atack, Jeremy, "Estimation of Economies of Scale in Nineteenth-Century United States Manufacturing and the Form of the Production Function," *The Journal of Economic History*, 1978, *38* (1), 268–270.

_ , *Estimation of economies of scale in nineteenth century United States manufacturing*, New York: Garland Publishing, 1985.

_ **, Fred Bateman, and Robert A. Margo**, "Steam power, establishment size, and labor productivity growth in nineteenth century American manufacturing," *Explorations in Economic History*, 2008, *45*, 185–198.

Atkin, David, Azam Chaudhry, Shamyla Chaudry, Amit K. Khandelwal, and Eric Verhoogen, "Organizational barriers to technology adoption: Evidence from soccer-ball producers in Pakistan," *The Quarterly Journal of Economics*, 2017, *132* (3), 1101–1164.

Balboni, C., O. Bandiera, R. Burgess, M. Ghatak, and A. Heil, "Why do people stay poor?," *mimeo*, 2021.

Banerjee, A. V., E. Breza, E. Duflo, and C. Kinnan, "Do credit constraints limit entrepreneurship? Heterogeneity in the returns to microfinance.," *mimeo*, 2019.

Banerjee, Abhijit, Emily Breza, Esther Duflo, and Cynthia Kinnan, "Can microfinance unlock a poverty trap for some entrepreneurs?," Technical Report, mimeo 2021.

Banerjee, Abhijit V., "Contracting constraints, credit markets, and economic development," in "Econometric Society Monographs," Vol. 37 2003, pp. 1–46.

_ **and Esther Duflo**, "Growth Theory through the Lens of Development Economics," in Philippe Aghion and Steven N. Durlauf, eds., *Handbook of Economic Growth*, Vol. 1A, Amsterdam: Elsevier, 2005, pp. 473–552.

Banerjee, Abhijit V and Esther Duflo, "Do Firms Want to Borrow More? Testing Credit Constraints Using a Directed Lending Program," *The Review of Economic Studies*, 2014, *81* (2), 572–607.

Bari, Faisal, Kashif Malik, Muhammad Meki, and Simon Quinn, "Asset-based microfinance for microenterprises: Evidence from Pakistan," 2021.

Bassi, Vittorio and Aisha Nansamba, "Screening and Signaling Non-Cognitive Skills: Experimental Evidence from Uganda," *Economic Journal*, 2022, *132* (642), 471–511.

Bergquist, Lauren, Benjamin Faber, Thibault Fally, Matthias Hoelzlein, Edward Miguel, and Andres Rodriguez-Clare, "Scaling Agricultural Policy Interventions: Theory and Evidence from Uganda," *Mimeo*, 2019.

Bloom, Nicholas, Aprajit Mahajan, David McKenzie, and John Roberts, "Why do firms in developing countries have low productivity?," *American Economic Review*, 2010, *100* (2), 619–23.

Broda, Christian and David Weinstein, "Globalization and the Gains from Variety," *The Quarterly journal of economics*, 2006, *121* (2), 541–585.

Brooks, Wyatt, Joseph P. Kaboski, and Yao A. Lee, "Growth policy, agglomeration, and (the lack of) competition," *mimeo*, 2018.

Buera, Francisco J, Joseph P. Kaboski, and Yongseok Shin, "Finance and development: A tale of two sectors," *American economic review*, 2011, *101* (5), 1964–2002.

_ , Joseph P Kaboski, and Yongseok Shin, "Finance and development: A tale of two sectors," *American economic review*, 2011, *101* (5), 1964–2002.

Buera, Francisco J., Joseph P. Kaboski, and Yongseok Shin, "The Macroeconomics of Microfinance," *mimeo*, 2017.

Burdett, Kenneth and Dale T. Mortensen, "Wage Differentials, Employment Size, and Unemployment," *International Economic Review*, 1998, *39* (2), 257–273.

Cai, Jing and Adam Szeidl, "Interfirm Relationships and Business Performance," *The Quarterly Journal of Economics*, 2018, *133* (3), 1229–1282.

Carranza, Eliana, Robert Garlick, Kate Orkin, and Neil Rankin, "Job Search and Hiring with Two-sided Limited Information about Workseeker's Skills," *mimeo*, 2020.

Caselli, Francesco, "Accounting for Cross-Country Income Differences," *Handbook of Economic Growth*, 2005, *1*, 679–741.

Caunedo, J and E. Keller, "Capital Obsolence and Agricultural Productivity," *The Quarterly Journal of Economics*, 2021, *136* (1), 505–561.

Caunedo, Julieta and Namrata Kala, "Mechanizing Agriculture Impacts on Labor and Productivity," 2021.

_ , _ , and Haimeng Zhang, "Economies of Density in Capital Rental Markets," *mimeo*, 2020.

Cavalcanti, Tiago V, Joseph P Kaboski, Bruno S Martins, and Cezar Santos, "Dispersion in financing costs and development," Technical Report, National Bureau of Economic Research 2021.

Chandler, Alfred D. Jr., *The Visible Hand: The Managerial Revolution in American Business*, Cambridge, Mass.: Harvard University Press, 1977.

_ , *Scale and Scope: The Dynamics of Industrial Capitalism*, Harvard University Press, 1990.

Chandrasekar, Arun, Melanie Morten, and Alessandra Peter, "Network-based Hiring: Local Benefits; Global Costs," *Mimeo*, 2020.

Coase, R. H., "The Nature of the Firm," *Economica*, 1937, *4* (16), 386–405.

Duranton, Gilles and Diego Puga, "Micro-foundations of urban agglomeration economies," in "Handbook of regional and urban economics," Elsevier, 2004.

Egger, Dennis, Johannes Haushofer, Edward Miguel, Paul Niehaus, and Michael Walker, "General Equilibrium Effects of Cash Transfers: Experimental Evidence from Kenya," *Mimeo*, 2019.

Ellison, Glenn, Edward L. Glaeser, and William R. Kerr, "What causes industry agglomeration? Evidence from coagglomeration patterns," *American Economic Review*, 2010, *100* (3), 1195–1213.

Foster, Andrew D and Mark R Rosenzweig, "Are there too many farms in the world? Labor-market transaction costs, machine capacities and optimal farm size," Technical Report 3 2022.

Greenwood, Jeremy and Boyan Jovanovic, "Financial development, growth, and the distribution of income," *Journal of Political Economy*, 1990, *98* (5), 1076–1107.

Griliches, Z., "Issues in Assessing the Contribution of Research and Development to Productivity Growth," *Bell Journal of Economics*, 1997, *10* (1), 92.

Grossman, Sanford J. and Oliver D. Hart, "The Costs and Benefits of Ownership: A Theory of Vertical and Lateral Integration," *Journal of Political Economy*, 1986, *94* (4), 691–719.

Hall, Robert E. and Charles I. Jones, "Why Do Some Countries Produce so Much More Output per Worker than Others?," *The Quarterly Journal of Economics*, 1999, *114* (1), 83–116.

Hardy, Morgan and Jamie McCasland, "Are Small Firms Labor Constrained? Experimental

Evidence from Ghana," 2020, *mimeo.*

Hart, Oliver and John Moore, "Property Rights and the Nature of the Firm," *Journal of Political Economy*, 1990, *98* (6), 1119–1158.

Heise, Sebastian and Tommaso Porzio, "The Aggregate and Distributional Effects of Spatial Frictions," Technical Report, National Bureau of Economic Research 2021.

Hsieh, Chang-Tai and Benjamin A Olken, "The Missing "Missing Middle"," *The Journal of Economic Perspectives*, 2014, *28* (3), 89–108.

_ and Peter J Klenow, "The life cycle of plants in India and Mexico," *The Quarterly Journal of Economics*, 2014, *129* (3), 1035–1084.

Janes, L., M. Koelle, and S. Quinn, "Do capital grants improve microenterprise productivity?," *CSAE Working Paper WPS/2019-13-v2*, 2019.

Jensen, Robert and Nolan H. Miller, "Market Integration, Demand, and the Growth of Firms: Evidence from a Natural Experiment in India," *American Economic Review*, 2018, *108* (12), 3583–3625.

Kaboski, Joseph P and Robert M. Townsend, "A structural evaluation of a large-scale quasi-experimental microfinance initiative," *Econometrica*, 2011, *79* (5), 1357–1406.

_ and Robert M Townsend, "A structural evaluation of a large-scale quasi-experimental microfinance initiative," *Econometrica*, 2011, *79* (5), 1357–1406.

Lucas, Robert E, "On the size distribution of business firms," *The Bell Journal of Economics*, 1978, pp. 508–523.

Macchiavello, Rocco, "A Mutually Beneficial Relationship: Relational Contracts in Developing Countries," in "A Research Agenda for New Institutional Economics," Edward Elgar Publishing, 2018.

Marshall, A, *Principle of Economics*, 8th edition ed., London: MacMillan, 1920.

McKenzie, David and Christopher Woodruff, "Business Practices in Small Firms in Developing Countries," *Management Science*, 2017, *63* (9), 2967–81.

Mel, Suresh De, David McKenzie, and Christopher Woodruff, "Returns to Capital in Microenterprises: Evidence from a Field Experiment," *The Quarterly Journal of Economics*, 2008, *123*, 1329–1372.

_ , _ , and _ , "Labor Drops: Experimental Evidence on the Return to Additional Labor in Microenterprises," *American Economic Journal: Applied Economics*, 2019, *11* (1), 202–35.

Melitz, Marc J., "The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity," *Econometrica*, 2003, *71* (6), 1695–1725.

Midrigan, Virgiliu and Daniel Yi Xu, "Finance and misallocation: Evidence from plant-level data," *American economic review*, 2014, *104* (2), 422–58.

Moll, Benjamin, "Productivity losses from financial frictions: Can self-financing undo capital misallocation?," *American Economic Review*, 2014, *104* (10), 3186–3221.

Olmstead, Alan L and Paul W Rhode, "Beyond the threshold: an analysis of the characteristics and behavior of early reaper adopters," *The Journal of Economic History*, 1995, *55* (1), 27–57.

Perla, J and C Tonetti, "Equilibrium Imitation and Growth," *Journal of Political Economy*, 2014, *122* (1), 52–76.

Rabellotti, Roberta, "Is there an "industrial district model"? Footwear districts in Italy and Mexico compared.," *World Development*, 1995, *23* (1), 29–41.

Rampini, Adriano, "Financing Durable Assets," *American Economic Review*, 2019, *109* (2), 664–701.

_ and Robert Townsend, "Renting for Development," in "2016 Meeting Papers" number 1296 Society for Economic Dynamics 2016.

Richardson, George B, "The organisation of industry," *The economic journal*, 1972, *82* (327), 883–

896.

Schmitz, Hubert, "Collective efficiency: Growth path for small scale industry," *The journal of development studies*, 1995, *31* (4), 529–566.

Shapiro, Jeremy, Chaning Jang, and Matthew Spitzer, "Evaluating the impact of physical and human capiral augmentation to drive small business growth in Kenya," *mimeo*, 2020.

Startz, Meredith, "The Value of Face-to-Face: Search and Contracting Problems in Nigerian Trade," *mimeo*, 2019.

Steenbergen, V. and B. Javorcik, "Analyzing the Impact of the Kigali Special Economic Zone on Firm Behavior," Technical Report F-38419-RWA-1, International Growth Center Policy Working Paper 2017.