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Supply preferences and productive electricity use constraints among micro and small enterprises in Bihar, India

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ABSTRACT

Productive electricity use is one channel by which improvements in electricity supply contribute to economic development. Literature in this context focusses typically on larger more established firms. Here we describe electricity supply, use and preferences among micro- and small-enterprises (MSEs), which are important providers of livelihoods in emerging economies. We conduct our work using primary surveys of firm owners (N = 696) in Bihar, India. We find that reported grid electricity supply reliability is quite good, providing on average 18.7 h of electricity per day and less than one day with blackouts or voltage fluctuation per month. Nevertheless, 40% of the sampled firms have no grid connection and 75% of consume less than one kilowatt-hour per day to power basic appliances including lighting, phone charging, and fans. Using a conjoint experiment to explore firm preferences for their electricity supply, we find that supply-side improvements are unlikely to drive broad increases in grid take-up and electricity consumption. Moreover, for the majority of firms, decentralised power supply through renewable energy technologies is both adequate and acceptable to firm owners, providing a viable parallel solution to grid extension.

Introduction

Although electricity access is widely considered a driver of economic development, contemporary evidence describing its effects on firm productivity in emerging economies is surprisingly diverse. Reliable and affordable electricity access can improve the productivity of existing business processes, increase local value addition and indeed unlock new business opportunities. The mechanisms and pathways for such benefits to materialise following improvements to electricity supply are, however, not straight forward. Three broad themes appear out of recent empirical literature that describe a more complex relationship and thus motivate our work. Firstly, it is unclear whether performance improvements and increasing levels of electricity consumption can be expected across all types of firms following electrification (Kassem, 2018; Peters et al., 2011). Secondly, the effects of access are intuitively modified by supply reliability, however this is specific to the subset of firms strongly dependent on electricity for productive processes. Those able to shift production are less affected, while those large enough can and do mitigate losses through self-generation (Allcott et al., 2016; Falentina & Resosudarmo, 2019; Moyo, 2013). Thirdly, the available evidence of firm energy use and preferences is largely drawn from bigger manufacturing and agro-processing firms, especially in the Indian context, with less known about the needs and preferences of micro- and small-enterprises that function as important sources of livelihoods in both urban and rural areas (Abeberese, 2017; Allcott et al., 2016; Ghosh & Kathuria, 2014).

Reflecting on these key themes, the work presented here contributes to our understanding of productive energy use and supply preferences in the context of micro- and small-enterprises (MSEs) in emerging economies. Specifically, our work draws on primary survey data gathered in Bihar, India, a state with historical poorer electricity supply that underwent recent reforms in the electricity supply sector. Given our focus on MSEs and the limited literature describing energy use in this sector, we begin with a discussion of firm types, size, employment and estimated electricity consumption. We then report subjective barriers to growth and other challenges from the perspective of firm owners. Building on this descriptive analysis, our main contribution is the application of a conjoint experiment to identify causal relationships between several dimensions of electricity supply and the likelihood for firms to accept the service.

Our work reveals that despite complete village electrification, over 40% of MSEs remain off-grid, citing affordability concerns. Reflecting on electricity use, we estimate that three quarters of firms consume <1 kWh hour per day, largely to satisfy a limited range of energy services. We find that reported grid electricity supply reliability is quite good, providing on average 18.7 h of electricity per day and less than one day with blackouts or voltage fluctuation per month. In comparison

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to other challenges faced by the firm, electricity reliability is also perceived as less important than issues in access to credit, bureaucratic corruption and timely payment by customers. These broad outcomes hold for both grid-connected and other non-grid firms in our sample. Our conjoint experiment then explores electricity supply preferences across a series of supply attributes including supply reliability, quality, adequacy, source and cost. We report three broad findings, i) hypothetical improvement to already quite good grid supply reliability in Bihar has a marginal effect on MSE preferences irrespective of the sub-groups we consider, ii) firms are unlikely to support increases in electricity supply costs (for example to cover further supply improvements), with this effect growing stronger among smaller firms with fewer assets, iii) firms do not present a preference for grid or mini-grid supply irrespective of whether they are grid-connected or not. Our work now begins with a review of the pertinent literature which we return to in the detailed discussion of our results.

Literature review

As discussed in the introduction, there are three broad themes in the literature with respect to productive electricity use in emerging economies that motivate our work, namely, (1) business productivity improvements following electrification are heterogeneous different types of firms, (2) similarly, firm dependence on reliable electricity supply for their productive processes is related to the sector in which they operate, and (3) there is a gap in empirical evidence describing the electricity needs and preferences of micro- and small-enterprises that function as important sources of livelihoods in both urban and rural areas. The remainder of this section is structured along these three themes.

(1) Early case studies on MSE development outcomes following grid electrification in Uganda and Benin found limited improvements to the performance of incumbent firms, though they did find structural changes in firm sectoral composition - essentially a shift in the types of firms active in electrified areas (Neelsen & Peters, 2011; Peters et al., 2011). In Benin for example, although electrified regions reported an increase in the number of firms with higher profits than regions without electricity (newer firms reflecting shifts in sectoral composition), incumbent small firms in these regions did not seem to share in these productivity gains (Peters et al., 2011). A key driver of the difference in outcomes between newer post-electrification and incumbent small firms is the ability to translate electricity into goods and services. Kassem (2018) found that while grid electrification in Indonesia increased the number of firms, as well as manufacturing output and total workers in the manufacturing sector, grid electrification also increased firm exit rates as more productive firms pushed out less productive firms. Supporting this idea of heterogeneous positive effects, Grimm et al. (2013) found that electricity access had no systematic effect on small and informal enterprise performance across seven major west-African cities, rather, that effects were dependant on sub-sector (such as clothing and tailoring firms). More recently, empirical work has highlighted the important modifying influence of market forces that strongly explained economic growth following electrification in villages proximate to local natural resources with high export demand (Fetter & Usmani, 2020). This suggests both that electrification effects are related to firm type such that electrification of a region causes changes in firm sectoral composition, and that these newer firms may be more likely to rely on and benefit from electricity as an input.

(2) Literature exploring the influence of supply reliability on firm performance and the propensity to self-generate describes similar trends. Analysis of the World Bank's enterprise surveys across sub-Saharan Africa found a general negative relationship between blackouts and food and agricultural firm productivity but not in garment making or chemicals (Moyo, 2013). This work also found that food and agricultural firms were more likely to operate generators, suggesting that these are less able to shift and store inputs during electricity shortages and have a stronger dependence on reliable power for production. More recent research on electricity shortages using the same dataset identified a causal effect leading to decreases in firms' sales overall, which were more severe for larger capital-intensive firms and were lessened among those owning a generator (Cole et al., 2018). Most closely related to our study context, the work of Falentina and Resosudarmo (2019) is the first to evaluate supply reliability and MSE performance, finding that electricity shortages had a negative impact on labour productivity among manufacturing MSEs in Indonesia, and that generator ownership offset the negative effects of shortages. While self-generation is an option for firms facing supply reliability issues, the ability to invest in this equipment is modified by firm wealth and size. Cissokho (2019) found that the relative costs of unreliable supply are higher for smaller Senegalese manufacturing firms unable to afford self-generation, aligning with Hardy and McCasland (2011) who found that small garment making firms in Ghana were negatively affected by blackouts, leading to working fewer hours, lower revenues and lower expenditures on wages. Similar outcomes are identified in the Indian context, where Allcott et al. (2016) found that electricity shortages led to productivity decreases in manufacturing firms, more severely affecting smaller firms and those that do not own generators. Self-generation with respect to captive diesel power generation remains, nevertheless, costly and less preferable to reliable supply from the national grid. Oseni and Pollitt (2015) found that while larger firms in across sub-Saharan Africa were more likely to operate captive power generation plants, losses due to grid supply reliability issues remained substantial due to fuel and operational costs. Similarly, Obokoh and Goldman (2016) found that almost all sampled small and medium manufacturing firms in Lagos, Nigeria were generating their own electricity and believed their profitability would improve if they were provided reliable electricity from the national grid. Interestingly, in China, electricity shortages were found to drive energy-intensive firms to shift from making intermediate goods using electricity to buying these from regions where power was reliable, rather than self-generating, highlighting the effects of the local context and market on firm decision to self-generate Fisher-Vanden et al. (2015).

(3) Finally, although literature describing alternatives and preferences for productive electricity supply in India exists, the evidence is somewhat limited with respect to micro- and smaller-enterprises. Ghosh and Kathuria (2014) report that Indian energy policy changes in 2003 encouraged captive power generation to alleviate supply-side constraints. Their descriptive analysis of firms in Andhra Pradesh aligns with the literature in finding that firm size as well as their dependence on reliable electricity for production explains the propensity to self-generate. With respect to supply preferences and costs associated with self-generation, Ghosh et al. (2017) found that small and medium firms engaged in manufacturing near Hyderabad were in fact willing to pay 20% more for reliable electricity supply from the national grid. On the other hand, Abeberese (2017) found that manufacturing firm output in India is linked to electricity price, such that their electricity consumption and productivity drops as electricity price increases. The most relevant evidence is found in the work of Allcott et al. (2016), which suggests that electricity reform in India in form of reduced prices for smaller firms unable to self-generate in exchange for accepting more frequent power outages could alleviate the negative impacts of outages due to their ability to store inputs when these occur. Nevertheless, the applicability of this evidence to micro- and small-enterprises with low levels of electricity consumption is somewhat uncertain.

The literature discussed here summarises the state of knowledge with respect to MSE electricity dependence and supply preferences in emerging economies. This is the point of departure for our empirical work and guides the research questions we consider. The focus of our work is on the largest gap in the literature - namely electricity supply preferences among MSEs in emerging economies. In exploring this question, we also describe actual productive electricity use as well as the characteristics of the MSEs themselves. Building on this foundation,

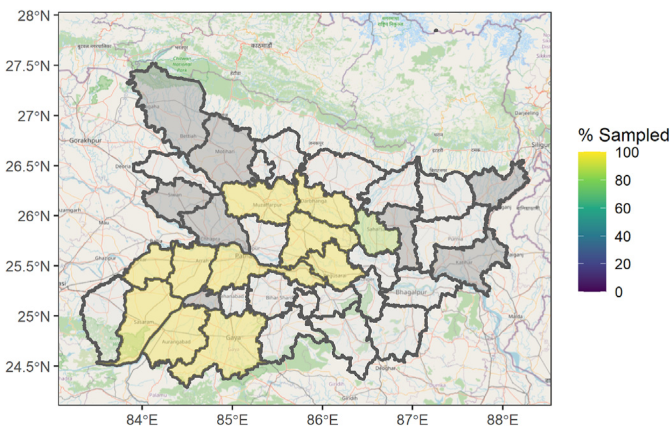

Fig. 1. Graphical depiction of the district sampling design and completion rate. Districts in grey were intended to be sampled, but were not completed due to the COVID-19 pandemic.

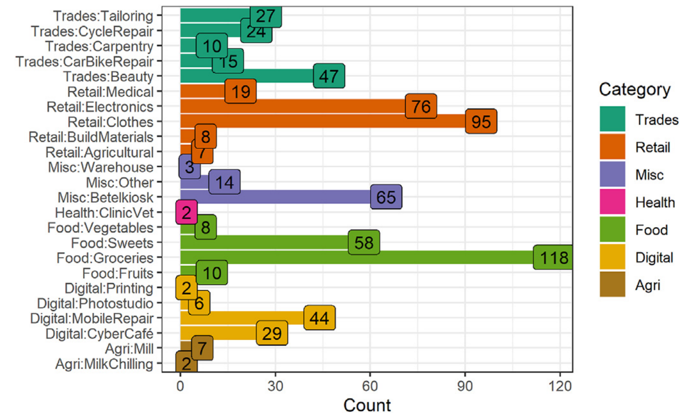

Fig. 2. A count of the different types of firms surveyed categorized by the type of goods or services offered (N = 696).

we now introduce our research design, data collection strategy and analysis approach.

Research design

Data collection

We use stratified random sampling to create a representative sample of MSEs across Bihar. Bihar is divided into 38 districts of which half (19) are randomly selected following probability weighting by the relative number of non-farm employed adults in each district. The relative number of non-farm employed adults is used to proxy the relative number of MSEs in the district as data for the latter at this level is not available. For each selected district, we then calculate the proportion of urban and rural villages/towns. This proportion is used to determine how many rural and urban villages/towns are selected for sampling, summing to total of 8 villages/towns from each district. The proportional share of rural and urban villages is taken to ensure that the probability weighted sample is not biased towards urban villages, as these will have a higher relative number of non-farm employed adults. The 8 villages/towns are finally selected following probability weighting by the relative number of non-farm employed adults in each village, stratified by urban/rural categories, in the respective district. In each town/village we interview 8 MSEs. These measures create an efficient self-weighted representative sample of MSEs across Bihar.

We rely on the Indian Government's definition of MSEs. Manufacturing MSEs are defined as manufacturing enterprises with <5 crore (50 million) rupees invested in plant and machinery. Retail and services MSEs are defined as retail enterprises with <2 crore rupees invested in equipment. During sampling, no specific preference was given to the sector in which the MSEs operated. That is, no specific instruction was given to avoid e.g. food processing or agricultural enterprises. Rather, enumerators were instructed to begin at the centre of the enumeration area and count all of the MSEs in the enumeration area. They were then instructed to split the enumeration area in half and visit every 'N'th enterprise in either direction from the centre of the enumeration area, where N is the total MSEs counted divided by the desired sample of 8 MSEs.

This sampling procedure results in the selection of 8 enterprises from each of the 152 villages/towns across 19 districts of Bihar, summing to 1216 enterprises. The data collection was unfortunately interrupted due to challenges following the outbreak of the COVID-19 pandemic in March 2020. We successfully sampled 10 of the 19 districts in the original sampling design (with an additional district where 56 of the required 64 enterprises were sampled), as shown in Fig. 1. In total, we have collected 696 completed surveys. While the sampled districts were not completed in a way that generates additional sampling bias, it is important to recognise that the sample is not technically representative of all of Bihar.

The distribution of firm types and operational categories in our dataset is shown in Fig. 2. The empirical cumulative distribution function plots of firm assets, monthly profits, monthly employee salaries (not including the owner) and engineering estimates of electricity consumption based on appliance time-use are shown in Fig. 3.[1] The data indicates that three-quarters of firms report total assets <50,000 INR and monthly profits of approximately 10,000 INR. Most MSEs have no full-time employees. Engineering estimates of electricity consumption for three-quarters of firms are below 1 kilowatt-hour (kWh) per day. Considering both the types of enterprises surveyed and the data discussed here, we are evidently working with a sample of varied but nonetheless quite small MSEs. As discussed earlier, this does not reflect any form of intentional selection bias in the sampling approach (other than ensuring we only select MSEs), but rather reflects the variety and prevalence of small owner-operator businesses in this context.

Descriptive analysis

Our descriptive analysis explores responses to questions regarding firm electricity use, electricity supply, business problems and hypothetical investment decisions conditional on supply improvement. The latter survey questions serve to describe the relative importance of electricity supply as compared to other business constraints. We explore differences in these responses between grid-connected and all other firms, and speculate as to what drives certain firms to remain without a grid-connection despite almost complete village and household electrification across Bihar.

With respect to energy access and use, firms were asked to objectively describe their electricity supply, appliance ownership and hours of utilisation. With respect to barriers and challenges, firms were asked to respond to a series of hypothetical scenarios using a mix of yes/no questions and Likert-scale questions (e.g. Not a problem, Minor problem, Major problem). Aggregate statistics of firm responses across these questions are presented exactly as they were asked. We estimate electricity consumption at firm level using reported typical usage hours for each appliance type the firm owns. These are multiplied by nominal power estimates (in Watts) drawn from past work (Agrawal et al., 2019). Appliances are categorized ex-post by energy service in order to enable estimation of i) usage of distinct energy services and ii)

[1] Further detail describing the engineering estimates and justification of this approach is provided in the following section.

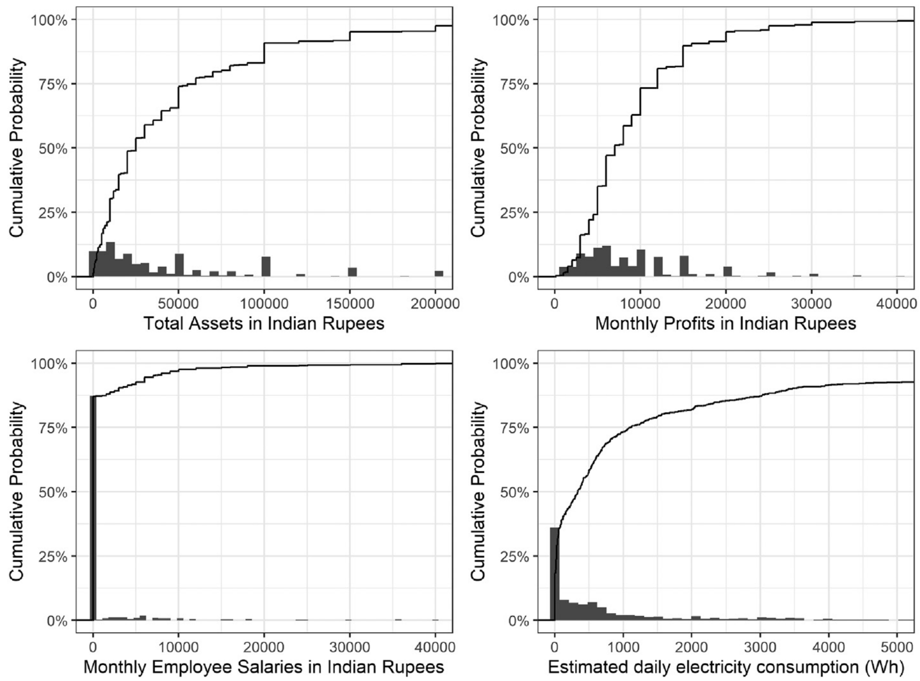

Fig. 3. Empirical cumulative distribution function plots of reported firm assets, monthly profits, monthly employee salaries and engineering estimates of daily electricity consumption for all firms (N = 696).

electricity consumption by energy service. Table 1 provides an overview of the energy service categories, associated appliance, ownership rates among grid and all other firms, and the nominal wattage estimates used in electricity consumption estimation.

Supply preferences

The goal of the conjoint experiment is to determine firm preferences for electricity supply across a range of attributes relevant to productive electricity use. We define these attributes as supply availability (hours per day), blackouts (days per month), voltage fluctuation (days per month), supply technology (grid or minigrid), supply adequacy (light and phone charging only, or all appliances), and cost. Enterprises are offered two distinct hypothetical electricity supply options from which they are asked to select their preferred option. Each supply option provides a different combination of attributes. There are thus two binary outcome variables per set of options, denoting which of the two offered electricity supply options the enterprises would prefer. Table 2 describes the attributes and levels tested.

Table 1
Energy services, corresponding appliances, nominal power consumption and differences in rates of utilisation among grid-connected and all other MSEs.

Service	Appliance	Nominal wattage	Utilisation (Grid)	Utilisation (All others)
Light	Light_Incand	100	5%	1%
	Light_CFL	15	14%	8%
	Light_LED	10	84%	44%
	Light_Tube	30	8%	1%
Phone	Mobile	5	62%	6%
Fans	Fan_Table	60	18%	8%
	Fan_Ceiling	70	61%	4%
IT	MusicSystem	15	10%	2%
	LaptopPC	50	16%	3%
	TV	30	3%	0%
	Printer	350	12%	1%
Fridge	Fridge	40	14%	0%
Mechanical	GrinderMixer	400	1%	0%
	AirCompressor	400	1%	0%
	Mill_FlourOil	7500	1%	0%
	Other>1 kW	1000	7%	0%
Thermal	Stove	1000	0%	0%
	Iron_Clothes	900	2%	0%
	Iron_Soldering	900	10%	4%
	Iron_Welding	5000	1%	2%
	HotAirGun	1000	5%	1%
	Laminator	200	8%	1%
	Other>1 kW	1000	2%	0%
Other	Scale	15	4%	1%
	Inverter	–	14%	2%

The conjoint experiment is conducted twice per respondent resulting in a total of 696 ∗ 2 ∗ 2 = 2784 observations (696 enterprises given two scenarios of which each has two electricity supply options). Analysis of the resulting data is conducted in line with Hainmueller et al. (2014). The model specification used in this analysis is:

$$\textbf{SupplyChoice}_{i,j,k} = \vec{\beta}_1\textbf{Availability}_{i,j,k} + \vec{\beta}_2\textbf{Blackouts}_{i,j,k} + \vec{\beta}_3\textbf{Fluctuation}_{i,j,k} + \beta_4\textbf{Power}_{i,j,k} + \beta_5\textbf{Grid}_{i,j,k} + \vec{\beta}_6\textbf{Cost}_{i,j,k} + \varepsilon_{i,j,k} \tag{1}$$

where i indexes enterprises, j indexes scenarios and k indexes electricity supply options. **SupplyChoice** is our outcome variable and represents a binary variable indicating whether or not the respondent chose a particular supply option. **Availability** is a vector options for the available supply duration over a typical day ranging from 6 to 24 h in increments of 6 h.

Table 2
Attributes and levels tested during the conjoint experiment. Two hypothetical options are created using these attributes, randomly selecting from the levels described within the square brackets.

Conjoint experiment attributes
Electricity is available [6, 12, 18, 24] hours per day
There are [0, 1, 5, 10, 15] blackouts per month
Voltage fluctuation happens [0, 1, 5, 10, 15] days per month
Electricity is strong enough to power [lights and phone charging only, any appliance you need]
Electricity is provided from [the grid, a microgrid]
Electricity costs [1, 5, 10, 15, 20, 25, 30] rupees per kWh

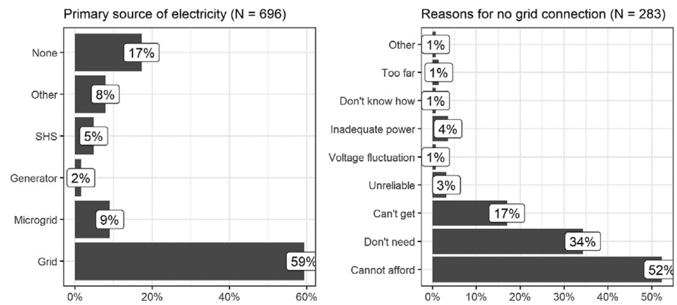

Fig. 4. Left: Primary source of electricity across all firms (N = 696). Right: Reasons for no grid connection among off-grid firms and those without any access to electricity (N = 283).

Blackouts is a vector of options (0, 1, 5, 10, 15) representing the average number of blackouts per month. **Fluctuation** is a vector of options (0, 1, 5, 10, 15) representing the number of days per month with voltage fluctuation that prevented or endangered the operation of electricity equipment. **Power** is a binary variable reflecting sufficient supply capacity to power any equipment as opposed to only lights and phone charging. **Grid** is a binary variable reflecting power supply from the Grid rather than a Microgrid. **Cost** is a vector of options (1, 5, 10, 15, 20, 25) representing the cost per unit (kWh of electricity) in rupees. $\varepsilon_{i,\,j,\,k}$ is a stochastic error term. Standard errors are clustered at the enterprise level to cater for unobserved characteristics potentially influencing their selection patterns.

We pre-registered a series of hypotheses relating to the conjoint experiment prior to data collection (10.17605/OSF.IO/AKSWJ). In summary, we stated that we believe respondents would be more likely to choose the supply option with longer supply availability per day, fewer blackouts per month and fewer voltage fluctuation days per month. We also stated that we believe respondents would be more likely to choose the supply option that enables them to power appliances beyond lighting and phone charging and equally likely to choose the grid or microgrid supply option.

We also estimate a variety of heterogeneous treatment effects to improve our understanding of underlying mechanisms driving the causal effects found in the conjoint analysis. For this exercise, we use the Bayesian Additive Regression Tree (BART) technique. BART is a non-parametric estimation technique that allows us to estimate heterogeneous treatment effects for multiple independent variables at the same time.

The intuition motivating this approach is to compare whether the likelihood that a firm chose, for example, low Cost electricity supply, is modified by specific features of the firm in aggregate terms. To use BART in this context, we create new dichotomous variables that reflect cases where the differences between the two scenarios presented to the firm (for a given attribute) were at their extreme. That is, in the example given at the start of this paragraph, we would create a new dichotomous Cost variable in the data for each scenario offered for each firm, such that if the firm was offered low Cost supply in a scenario (using the most extreme low Cost value, which is 1 rupee per kWh) we set this to 1 and all other scenarios (5–30 rupees per kWh) to 0. We can then interact this variable with key firm-level attributes to reveal how firm preference for low Cost supply varies conditional on the variables relating to our hypotheses described below.

In particular, we are interested in understanding whether i) the existing electricity supply and ii) the existing electricity utilisation modify electricity supply preferences. To justify the former, we believe that firms that are currently grid connected may have different preferences to those that remain off-grid. To justify the latter, we expect that enterprises consuming more electricity will have different preferences to those consuming very little. Enterprise electricity utilisation is measured by the number of different energy services[2] an enterprise is currently using electricity to power. We also adjust for firm wealth using their total assets as a proxy, and the category of the firm (shown in Fig. 2). The reasoning for this adjustment is to separate out firm-category and wealth effects that may confound the relationships we are interested in exploring.

In our pre-analysis plan, we stated that we believe both grid-connected firms, and those using many energy services will be more likely to choose the supply option with longer supply availability, fewer blackout days and fewer voltage fluctuation occurrences than off-grid firms and those using fewer energy services. The rationale here is that better quality electricity supply will be valued higher by enterprises more reliant on energy services for converting inputs into goods and services. Following this, we also expect that enterprises using more distinct energy services will be less sensitive to cost as they require these to operate their business.

Results

Descriptive analysis

Despite complete village electrification and near complete household electrification across Bihar as reported by the Government, we find that a substantial number of micro- and small enterprises (MSEs) continue to operate without a national grid connection, as shown in Fig. 4. 60% (N = 413) of the sampled enterprises report having a connection to the national grid, 23% (N = 163) utilise off-grid sources exclusively and the remaining 17% (N = 120) report no use of electricity whatsoever. When questioned as to the reason for not connecting to the national grid, the majority of non-grid enterprises reported *poor affordability* (53%), followed by *no necessity* (35%), and *unable to connect* (17%). It is notable that supply quality issues are seldom the reason that firms remain without a grid connection, rather, affordability constraints, a perceived lack of utility and an inability to connect seem to be the predominant driver from the perspective of MSE owners.

We explore this further in Fig. 5, separating firms that were grid-connected and comparing these against firms that remain off-grid for one of the top three reasons. This figure shows that grid-connected firms are generally larger relative to other firms, especially relative to those stating an inability to afford connection. Intuitively, we also observe some heterogeneity across firm category such that firms providing digital services are mostly grid-connected whereas those engaged in trades are more mixed. Interestingly, while our sample contains more urban firms given the proportional probability weighted sample design, it would appear that larger share rural firms are grid-connected. It follows that urban centres attract more MSEs which may be smaller and not necessarily require a grid-connection to operate, such as betel kiosks and small groceries vendors. While we do observe clear differences in terms of firm size and category, even after grid connection, 75% of firms report consuming on average <2 kWh of electricity per day. The low level of electricity consumption even among grid-connected MSEs reflects the fact that the majority of firms mainly

[2] Energy services are defined as Lighting, Phone Charging, Space Cooling, Digital Technologies, Refrigeration, Mechanical Work and Thermal Work. These services are linked to appliances which an enterprise might own.

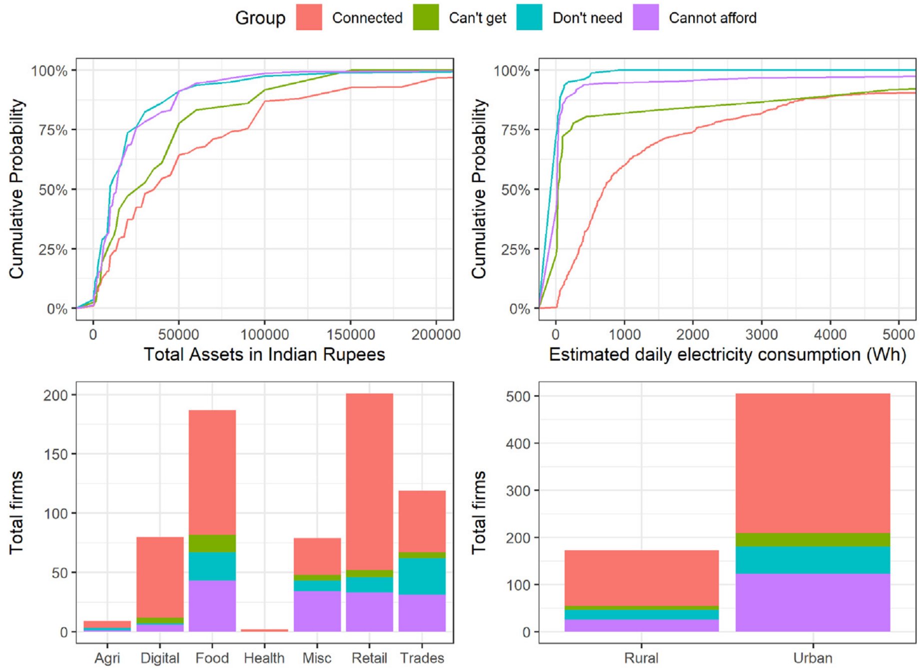

Fig. 5. Empirical cumulative distribution function plots of firm characteristics grouped by whether they are connected to the national grid, or stated one of three top reasons for not connecting corresponding to Fig. 4. Grouping was done in a cascading manner from *Cannot afford*, to *Don't need*, to *Can't get* as firms could choose more than one option. Firms reporting another reason for remaining off-grid were removed such that N = 676. Plots compare these groups across reported firm assets, engineering estimates of daily electricity consumption, firm category and rurality.

use lighting, phone charging and fan (space cooling) energy services. This is shown in more detail in both Fig. 6 and Table 3, which describes average electricity consumption rates by energy service, across both grid-connected and all other MSEs.

Could the low electricity consumption levels be related to supply reliability concerns? Reported multi-dimensional electricity supply indicators reveal that grid supply quality is reasonably high, suggesting that this is unlikely. Grid electricity supply is reported to be available on average for 18.7 h per day, with an average of 1.3 blackout days and 0.6 voltage fluctuation days per month as shown in Fig. 7.[3] Broadly speaking, with such levels of grid-supply, it would appear unlikely that supply quality concerns are strongly modifying consumption across the average grid-connected MSE.

To explore how this finding sits alongside other business challenges, both grid-connected and off-grid electrified firms were asked to rate the severity of selected problems faced by their business across a three-level scale: none, minor, major. All of the possible business challenges queried are shown in Fig. 8. As expected, it appears that reliable electricity access was not found to be a current concern. Rather, timely payment by customers for goods and services, access to credit and corruption were the most pressing problems, notably among both grid-connected and all other electrified firms.

It is evident that current supply reliability is less of a concern among both grid-connected and off-grid firms relative to other problems, but what of supply affordability? We asked firms to report whether the supply they receive, be it on- or off-grid, is reliable, affordable and adequate to power necessary appliances, shown in Fig. 9. The perception among Bihari MSE owners is that while the electricity supply they receive is broadly both reliable and adequate, affordability is a problem for a minority of firms. This aligns well with all of the earlier findings and underlines that the primary ongoing concern with both grid- and off-grid supply is cost. This is not to say that affordability of supply is necessarily a barrier to business growth, but rather that this is the

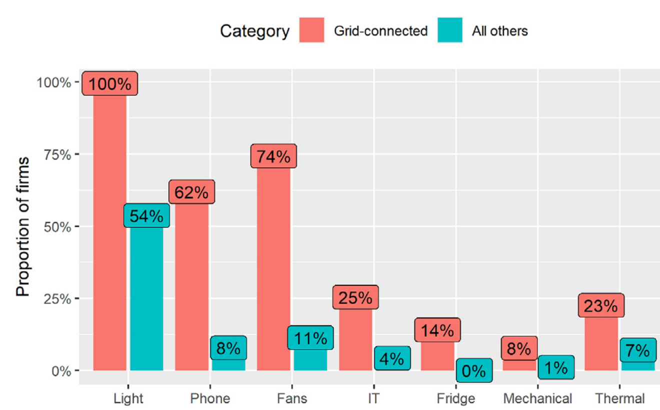

Fig. 6. Electrical energy services used by grid-connected and all other MSEs based on appliance ownership and use.

Table 3
Differences in average daily electricity consumption (in watt-hours) by energy services between grid-connected and all other MSEs.

	All others (N = 283)		Grid-connected (N = 413)		Diff. in means	Std. Error
	Mean	Std. Dev.	Mean	Std. Dev.		
Light	29	48	184	257	155	13
Phone	1	2	6	9	5	0
Fans	32	109	328	302	297	16
IT	34	313	259	877	225	47
Fridge	0	0	38	138	38	7
Mechanical	0	0	782	4756	782	233
Thermal	447	2406	871	3989	423	243
Other	0	4	2	12	2	1

[3] In reflecting on this one should consider it as common in this context for electricity supply to be rationed on a daily basis. Blackouts are considered as a separate unscheduled outage. Daily hours of supply are therefore reported as the standard rationed supply on an average day, which may well be <24 h.

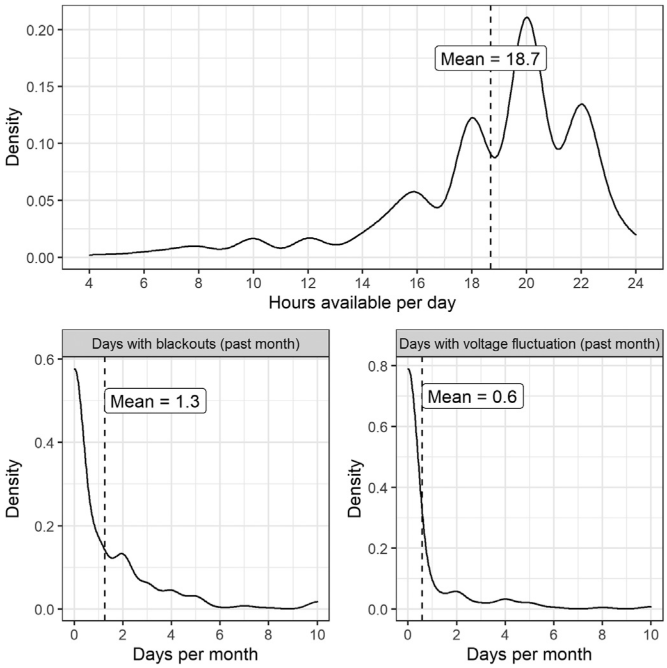

Fig. 7. The reported grid electricity availability, blackout frequency and voltage fluctuation frequency among grid-connected MSEs (N = 413).

most acute issue relative to the other attributes of supply, which are quite good overall.

Following on from this, we posed a hypothetical reduction in grid electricity prices to grid-connected firms and queried their interest in expanding their businesses across distinct aspects as shown in Fig. 10. Given the subjective nature of these questions, the aggregates should be considered relative to one-another rather than in isolation. Without speculating as to whether firms would actually be in the financial position to invest in new equipment or appliances following reductions in grid electricity price, we do take note that the likelihood to expand the workforce is relatively low compared to other aspects offered. This difference is key in our interpretation of this battery of questions. We explore this further in Fig. 11 which describes aggregate differences in firm assets and estimated electricity consumption grouped by the responses to this hypothetical drop in grid price. This suggests that it is larger firms and those with higher current electricity consumption that would exhibit stronger price elasticity, with the gap growing widest among those that would hire more employees. This summarises the puzzle that we explore in the next section. Is affordability indeed a constraint? How is this modified by current electricity consumption, firm wealth and firm sector?

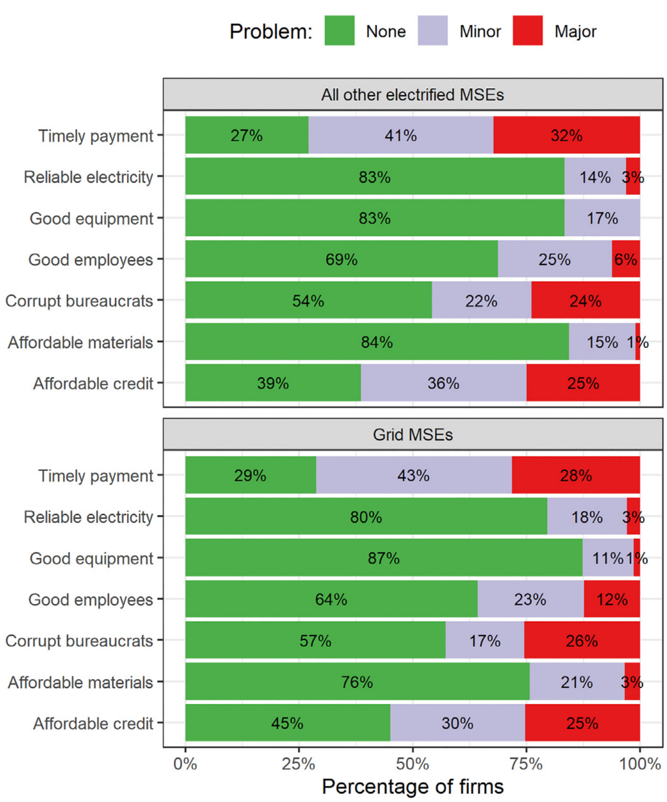

Fig. 8. The stated severity of problems faced by grid-connected (N = 413) and electrified off-grid MSEs (N = 163).

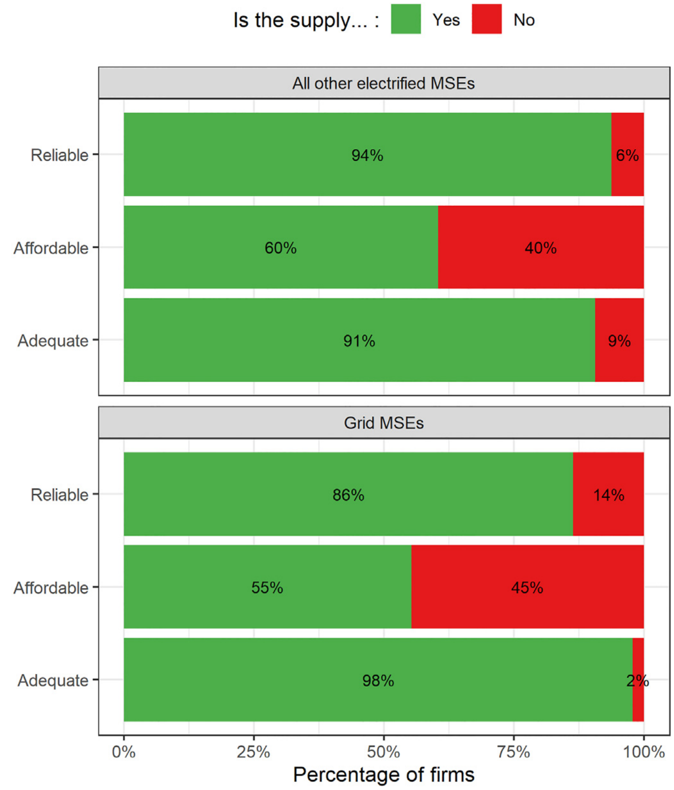

Fig. 9. Perception of supply reliability, affordability and adequacy among grid-connected and all other electrified MSEs (N = 576).

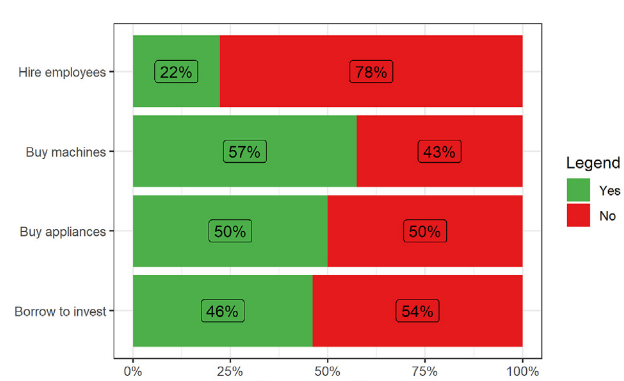

Fig. 10. Stated responses to a hypothetical drop in electricity prices among grid-connected MSEs (N = 413).

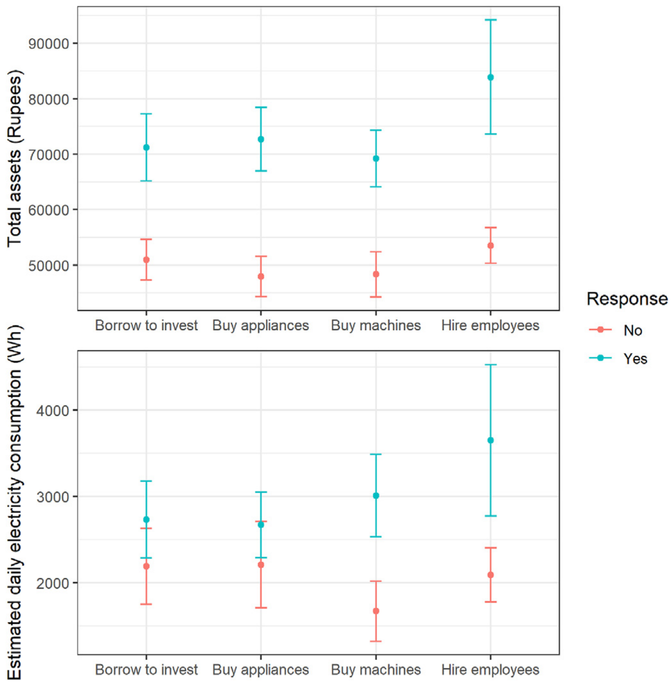

Fig. 11. Differences in mean firm assets and electricity consumption grouped by responses to a hypothetical drop in electricity prices among grid-connected MSEs (N = 413). 95% confidence intervals are shown as error bars.

Supply preferences

We now analyse electricity supply preferences derived from the conjoint experiment conducted with our full sample of MSEs. Fig. 12 describes the change in predicted probability of MSEs accepting an electricity service associated with a change in a specific attribute relative to a chosen baseline, averaged over the joint distributions of the other attributes.

To contextualise our analysis, we set the baseline dimensions of each electricity supply attribute to that which is provided by the national grid (based on mean values from our sample) as described above. We also set the cost baseline to reflect the dimension closest to the current kWh price in Bihar, which is approximately 6 INR. In doing so, we can evaluate the effects of improvement relative to the current level of grid supply in aggregate terms, across our sample of MSEs. The coefficients and standard errors describe the change in predicted probability of an enterprise accepting an electricity service related to a change in an attribute, relative to the chosen baseline within that attribute's possible dimensions.

First, we see that improvement in average grid supply availability (hours per day) from 18 to 24 h supply does not significantly shift the likelihood of MSE owners selecting the electricity service, whereas dropping this does. A drop in supply availability from 18 to 12 h (the next lowest level) reduces the predicted likelihood by 7.4%-points [95% CI: 2.0 to 12.7].

Next, we find that MSE owners seem to be more sensitive to days with blackouts rather than days with voltage fluctuation. An increase in days with blackouts from 1 to 5 results in a drop in predicted likelihood of 9.5%-points [3.7 to 15.3], whereas the point estimate for the same drop in days with voltage fluctuation was small and not statistically significant. The latter result rebuts our pre-registered hypothesis, and suggests that blackout days and voltage fluctuation days should not be given the same weight in developing targets or frameworks for guiding productive electricity supply provision among smaller firms.

Notably, MSE owners do not seem to be concerned as to whether the supply is provided by the national grid or a minigrid, as long as they are able to power the appliances they need. Restricting MSE appliance usage to only lighting and phone charging reduces the predicted probability of accepting the energy service by 28.3%-points [24.0 to 32.8]. This aligns with our pre-registered hypothesis, confirming that there is no inherent preference for grid supply in our sample of MSEs in Bihar. This suggests that policy makers could consider complementary off-grid power supply systems in future electricity supply reform.

We find that MSE owners are indeed somewhat sensitive to increases in price, though this is less clear in terms of price reductions. A 100% increase in price from 5 INR (the level closest to the current price of approximately 6 INR) to 10 INR results in a reduction in predicted likelihood of a firm accepting the service by 9.3%-points [2.6 to 15.0]. This relationship follows a somewhat linear trend for increases in price up to our limit of 30 INR. As reported earlier in this work, our descriptive results focussed on hypothetical responses to price reductions and found mixed results. The evidence here underlines this finding, suggesting that further reductions in electricity price are unlikely to shift MSE connection likelihoods, whereas increases in price would have a clear negative effect.

We note in our descriptive analysis that our sample of firms includes both those that do and do not currently use the national grid, as well as firms that use a range of energy services and those that just use lighting and phone charging. Do we observe heterogeneity in our main results when we group by these characteristics?

Fig. 13 shows that larger, grid connected firms and those using more energy services are less likely to accept supply options restricting use of appliances to phone charging and lighting, relative to off-grid firms and those using fewer energy services. Despite the observed heterogeneity, all sub-group probabilities lie below the baseline 50% probability, indicating that the main results are nevertheless applicable to all groups we consider.

Fig. 14 indicates that larger, grid-connected firms and those and that use more energy services are slightly more likely to accept a higher cost electricity service, suggesting a dependence on electricity for their businesses and a higher ability to pay for electricity. This aligns with our pre-registered hypothesis, and indicates that electricity cost changes will have heterogeneous impacts on firms, predominantly to the detriment of smaller firms that have already stated the challenge of affordability as a hindrance to grid-connection.

We find limited heterogeneity across the other attributes of supply. Contra to our pre-registered hypothesis, we find that both grid-connected firms and those currently using many energy services are no more interested in 24 h electricity supply than off-grid firms and those using only lighting and phone charging. A similar lack of heterogeneity in outcomes is evident regarding supply options providing fewer blackout days and fewer voltage fluctuation days. Finally, we find that enterprises are less concerned as to whether they are connected to the national grid or a minigrid, regardless of whether or not the firm is currently grid-connected or is using several energy services. This is a key finding in our work, suggesting that electricity policy reform can include both grid and off-grid supply options with respect to productive electricity use among urban and rural MSEs.

In summary, we argue that our main conjoint experiment results regarding supply source, availability and reliability are broadly applicable for both grid-connected and off-grid firms, as well as those consuming varying amounts of electricity. Supplementary results supporting these conclusions are described in detail in Appendix Section A1.

Conclusion and policy implications

In this work, we discuss the results of a survey of 696 micro- and small-enterprises (MSEs) sampled systematically across Bihar, India. Our work thus specifically targets the very smallest of enterprises that support poorer populations in both urban and rural areas. We analyse both firm characteristics as well as their responses to a conjoint experiment revealing preferences with respect to hypothetical electricity supply options. We draw two conclusions from our work that contribute to our understanding of MSE energy needs and supply preferences. First, we find that electricity supply reliability and cost do not appear to

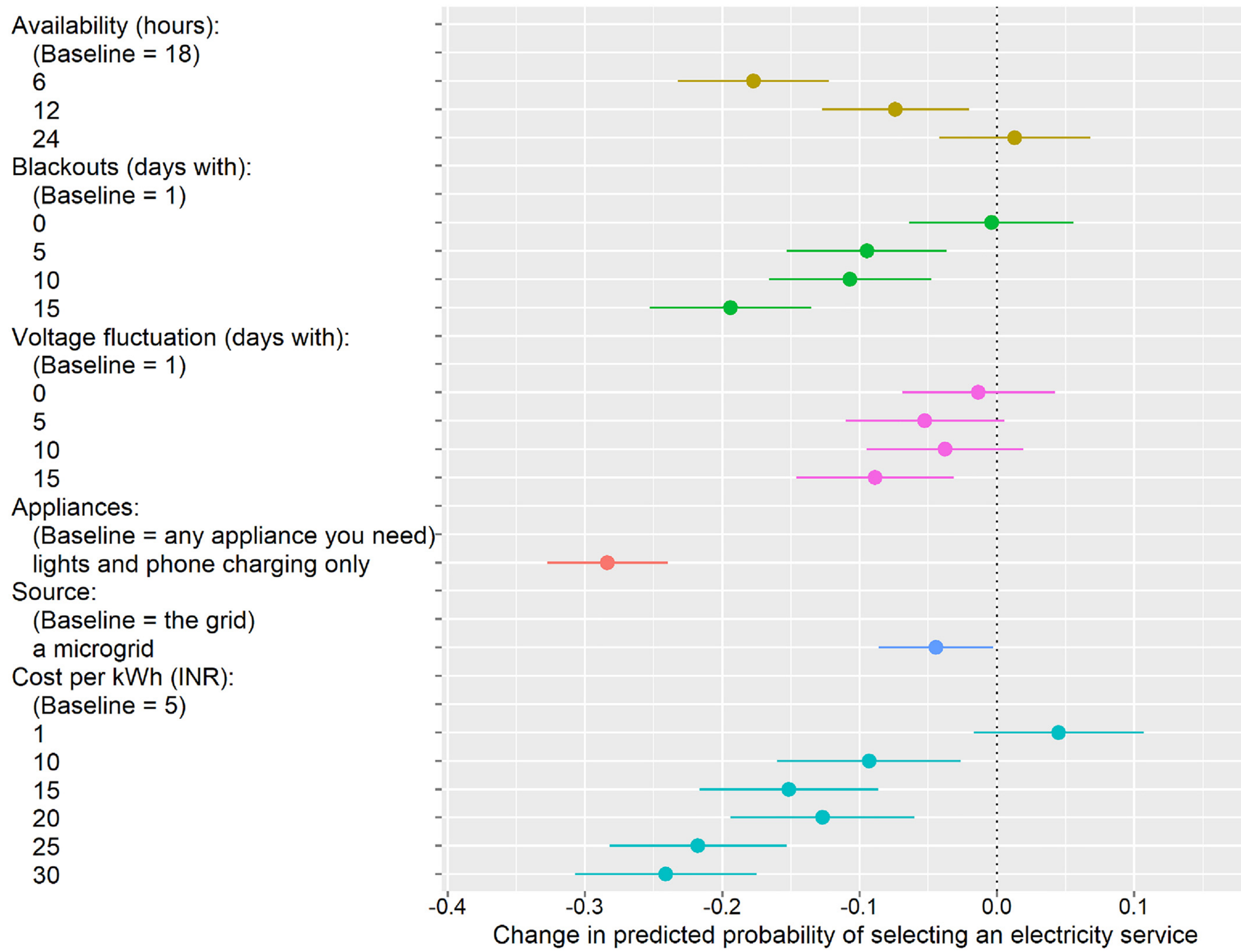

Fig. 12. Main conjoint experiment results: Change in predicted probability of MSEs accepting an electricity service conditional on aspects of that service. Coefficients describe the change relative to the chosen baseline within each attribute. Standard errors are clustered at enterprise level.

be a major constraint in aggregate terms across our sample of MSEs in the specific context of Bihar. Rather, we speculate that for the firms surveyed, the capacity to acquire new appliances and modify existing productive processes to take advantage of electricity are key barriers. Secondly, we find both that the limited energy services used by the majority of MSEs could be provided with decentralised technologies and that this is entirely acceptable to the firms themselves, identifying no inherent bias towards the national grid.

We contextualise our work with a descriptive analysis of the primary mode of electricity access, namely the grid supply quality. MSEs report that grid supply quality is quite good, providing on average 18.7 h of supply per day and <1 day with blackouts or voltage fluctuation. Corresponding to this, from the perspective of both off-grid and grid-connected firm owners, supply reliability is subjectively less of a concern relative to issues of corruption, access to finance and timely payment of customers. Nevertheless, while supply reliability appears quite good, 40% of MSEs remain off-grid, of which slightly less than half use no electricity whatsoever.

Affordability concerns are reported as the primary reason for remaining off-grid by approximately half of these firms. These firms are also typically much smaller and report lower profits than their grid-connected counterparts. We speculate that for these firms, front-loaded appliance costs and to a lesser extent, electricity expenditures may be simply too costly relative to the expected productivity gains. We find support in this interpretation given that a non-negligible share of these firms also state that they 'do not require' a grid-connection for their operations. Thinking this through, it may be the case that appropriate appliance finance could reduce the upfront cost barrier and improve the immediate business case, even among the smallest firms. Indeed there is evidence of the private sector targeting this gap by developing bespoke financial products for the purchase of equipment for small enterprises in the sub-Saharan African context (Trotter, 2021), suggesting an avenue for further research. Shifting our attention to grid-connected firms, we find that affordability is also a concern for a sizeable share of firms within this subset. However, the concern here appears to be functionally different between larger and smaller firms. While smaller grid-connected firms may consider the supply cost a problem, this is somewhat similar to the off-grid firms in that it is unlikely that reductions in cost would result in increased electricity consumption and business growth, as this is constrained by wealth and the current appliance stock. For these firms, it would appear that a threshold level of energy consumption given current appliance stock (i.e. lighting and fans) has been achieved, with further capital outlay required to modify productive processes and increase productive electricity utilisation. Their concerns are more likely to be with respect to electricity expenditures reducing their profitability rather than constraints to growth. Larger grid-connected firms, on the other hand, appear to be in a better position to translate savings in electricity costs into investments in the business and higher electricity consumption. For this subset of firms, reductions in cost may motivate extending

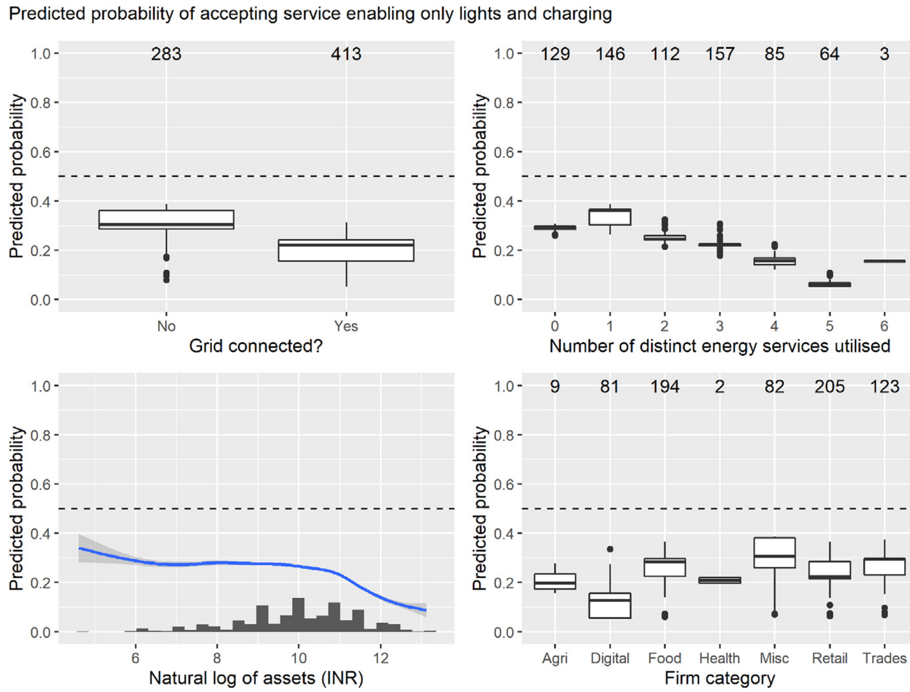

Fig. 13. Exploring heterogeneous treatment effects: Predicted probability of MSEs accepting an electricity service restricting usage to lights and phone charging, opposed to all appliances. The y-axis represents the predicted probability across the different levels of our conditioning factors shown on the x-axis. The count of unique MSEs in each group is displayed above the boxplots. The dashed line indicates the baseline 50% probability of selecting a service.

productive operating hours of existing equipment, expansion of the appliance stock and indeed hiring more employees.

The results of the conjoint experiment support this interpretation, revealing a stronger dependency on electricity among larger firms and, intuitively, among those utilising more energy services. Overall, the results of the conjoint experiment indicate that electricity reliability and costs are unlikely to be a serious business constraint among the majority of Bihari MSEs, notwithstanding the minority larger firms that may indeed respond positively to reductions in electricity costs. The main policy challenges regarding productive electricity use among these firms appears to be their limited capabilities to purchase appliances and modify existing productive processes. This indicates that policy reform in Bihar aiming to encourage productive electricity use among MSEs should look beyond supply improvements towards productive electricity use stimulation.

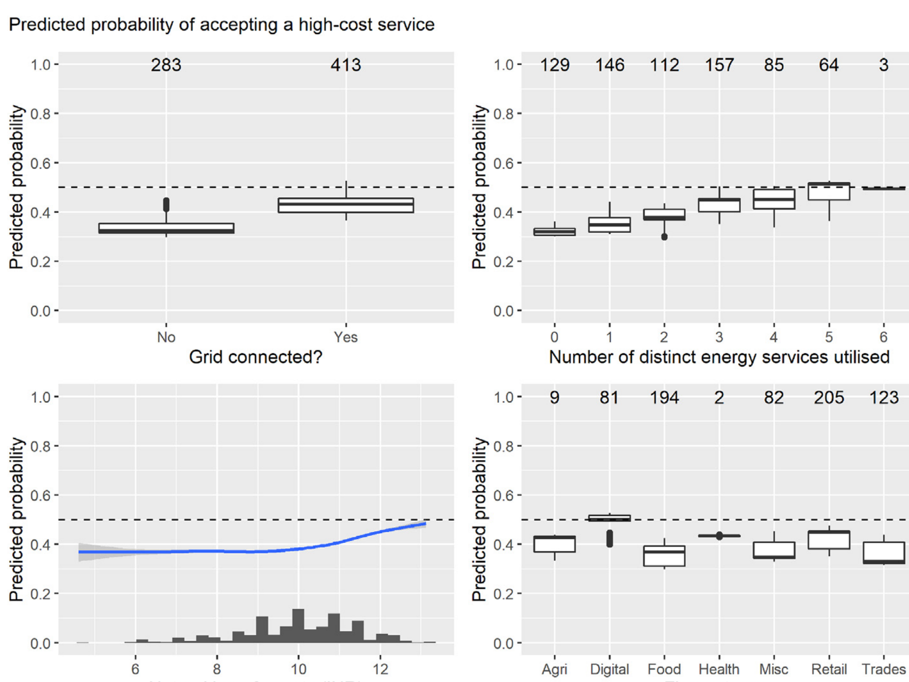

Fig. 14. Exploring heterogeneous treatment effects: Predicted probability of MSEs accepting a high-cost electricity service. The y-axis represents the predicted probability across the different levels of our conditioning factors shown on the x-axis. The count of unique MSEs in each group is displayed above the boxplots. The dashed line indicates the baseline 50% probability of selecting a service.

The distinct price elasticities discussed in our work are not a contradiction, but rather indicate that this is modified by current appliance stock and corresponding level of electrification of processes within the business. Earlier work describes similar outcomes among (pre-electrification) manufacturing firms as well as consolidation of the market following electrification in Benin and Indonesia (Kassem, 2018; Peters et al., 2011). In this literature, incumbent firms' performance either did not improve following electrification or did so for a minority of newer more productive firms which grew quickly and captured larger segments of the market. Reflecting on this, we also find some parallels in literature describing household electricity consumption and price elasticity in the Indian context. Household electricity consumption is similarly constrained by the ability to purchase appliances, such that at low levels of consumption, prices are less relevant as they reflect marginal changes to the final cost of energy services (Sankhyayan & Dasgupta, 2019). That is, once some level of electricity consumption is reached given the existing appliance stock, this is not likely to shift due to reductions in price without additional capital outlay for new appliances that may be out of reach. Low-levels of appliance ownership following grid-electrification in rural Rwanda and the lag between electricity access and appliance acquisition in India provide further examples of this constraint (Lenz et al., 2017; Richmond & Urpelainen, 2019).

Productive electricity use is nevertheless distinct from household energy service provision as the former reflects a business decision that may rapidly increase productivity. The policy challenge is therefore one of improving the balance between energy service costs (encompassing appliances, equipment and electricity) and increased revenue expectations. Our analysis therefore points towards two possible avenues for policy intervention targeting smaller and larger firms separately. First, the immediate wealth constraint faced by smaller MSEs could be addressed through both affordable finance combined with incentives for energy efficient appliance purchase (lights, televisions and fans), and the reduction of connection costs. These interventions would serve to generate demand among smaller firms that either chose to remain off-grid due to cost concerns or due to the lack appliances, however it is likely that a substantial share of this subset of firms will remain off-grid and report higher exit rates as the market consolidates. Second, providing loan guarantees to larger grid-connected MSEs would improve access to affordable credit for productive equipment purchases currently out of reach due to the stated liquidity constraints. Such demand-side interventions appear to be necessary at least in the short to mid-term to accelerate electricity consumption while also alleviating a primary non-energy concern raised by firms, namely access to affordable credit.

Finally, we also find that MSEs are agnostic to the electricity source, and would equally accept service through microgrids or standalone solar as long as they enable the utilisation of desired appliances at a price point similar to that provided by the grid currently. Reflecting on the low levels of electricity consumption we argue that this is entirely plausible for a range of scenarios. For example, in communities where the grid distribution infrastructure is under-developed (such as incomplete hamlet electrification), where formal connection requirements are unable to be met or where connection is constrained by institutional limitations resulting in severe delays following application. This follows similar conclusions in prior work discussing the role of decentralised supply in parallel to grid-connection for household electrification (Grimm et al., 2020; Heynen et al., 2019; Sievert & Steinbuks, 2020). Another possible avenue for policy intervention supported by our work is therefore the creation of incentives for decentralised electricity supply through solar microgrids and standalone solar solutions for small-scale productive use. Such systems can be designed to enable grid-interconnection should this become feasible in the future while providing MSEs with low-cost access that enables the utilisation of basic appliances they are currently in a position to acquire.

While the policy suggestions described here remain speculative in nature, our work shows that this is largely a demand-side challenge, requiring policy interventions to stimulate currently low productive electricity use among Bihari MSEs. Such interventions are not only important for continued MSE growth in Bihar, but also for the health of electricity distribution companies tasked with capturing sufficient revenue to operate and maintain supply infrastructure that has rapidly expanded over the past decade.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.esd.2022.01.004.

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