Communication and the organization of firms across space

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Abstract

This paper studies how adapting the hierarchical organization helps firms alleviate the negative impact of geographic frictions between their establishments on their performance. We document that multi-establishment firms empirically have more management layers than comparable single-establishment firms. Greater distance between subordinate establishments and headquarters reinforces the effect. We develop a model to understand the interplay of the number of establishments and the optimal hierarchical organization of a firm. We assume that the knowledge of the CEO is a resource of limited supply for a firm, because the CEO has a limited amount of time. The model shows that adding a layer of management at one establishment increases the efficiency of the use of CEO time in multi-establishment firms and has repercussions for the optimal hierarchical organization of the other establishments. The model mechanism explains both the cross-sectional differences between the organization of single and multi-establishment firms and patterns of their reorganization over time.

JEL codes: D21, D22, D24.

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1 Introduction

Growing firms often choose to organize their employees in multiple establishments at different locations. In fact, the largest firms typically are multi-establishment firms. Having several establishments allows firms to tap local labor markets and benefit from lower wages, for example. At the same time, there is increasing evidence that distance between subordinate establishments and the headquarters and other geographic frictions adversely affect the performance of multi-establishment firms (e.g. Giroud, 2013; Charnoz et al., 2015). Anecdotal evidence suggests that adjusting the hierarchical organization may help firms mitigate the impact of geographic frictions and fully reap the benefits of geographic expansion. For example, employing middle managers at regional offices instead of the headquarters was a key ingredient for the success of Singer Sewing Machine in the US (Chandler, 2002, p. 403-5). Philips employed dedicated country managers and regional executives as part of a larger strategy to revitalize their operations after 1996 (Nueno and Ghemawat, 2002). And when the Canadian manufacturing company Blinds To Go set up a manufacturing plant in New Jersey, moving an experienced manager on site proved vital to improve the new plant's production efficiency (Menor and Mark, 2001).

Still, we know little if anything about the influence of firm geography on the optimal hierarchical organization of firms. Recent papers have formalized the idea that adding a layer of management allows firms to use the time and knowledge of the employees more efficiently, and have assembled systematic empirical evidence that firms add layers as they grow to maintain their productivity (e.g., Caliendo and Rossi-Hansberg, 2012; Caliendo et al., 2015a, b). But existing studies assume that firms are single-establishment firms. They neither empirically nor theoretically take firm geography into account.

This paper studies how the decision to allocate employees to several establishments affects the optimal hierarchical organization of firms. We assemble a new detailed linked firm-establishment-employee data set from administrative sources in Germany that is ideally suited to compare the organization of single and multi-establishment firms. We contribute to the empirical literature on firm organization by first documenting systematic differences between the organization of single and multi-establishment firms. The differences exist conditional on size and other firm characteristics. To explain these differences, we develop a theoretical model of optimal multi-establishment firm organization. The model is based on the idea that firms organize employees in order to efficiently use their time and knowledge, and takes geographic frictions between subordinate establishments and the headquarters explicitly into account.

We uncover three facts about the organization of multi-establishment firms. First, we document that multi-establishment are more hierarchical than single-establishment firms: they have a higher number of management layers. Differences in the firm size—the well-known determinant of hierarchical organization—do not explain the differences in the number of layers; neither do differences in the legal form, sector or location. The impact of being a multi-establishment firm on the number of layers is sizeable and quantitatively equivalent to the effect of doubling the number of non-managerial employees.

Second, firm geography affects multi-establishment firm organization. Given firm size, the

number of managerial layers of multi-establishment firms increases with the distance of the subordinate establishments to the headquarters and with the area that the establishments cover. The managerial organization thus not only depends on whether a firm is single or multi-establishment, but on the specific geography.

Finally, we study the evolution of firms' hierarchical organization over time. We document that multi-establishment firms reorganize gradually and add or drop layers establishment by establishment. An analysis of the dynamics of multi-establishment organization at the firm level thus misses important margins of adjustment. To understand whether the difference in the number of hierarchical layers at the firm level is driven by headquarter or subordinate establishment organization, we compare the number of layers of headquarters of single and multi-establishment firms of the same firm size. The headquarters of multi-establishment firms have a lower number of hierarchical layers. This suggests that multi-establishment firms add layers at subordinate establishments first, and that these additional layers have repercussions for the headquarter organization, i.e. that establishment organization is interdependent.

Why does the number of establishments affect firms' hierarchical organization? We propose a model to explain why firms choose to organize their employees in multiple establishments, and why this decision affects the optimal hierarchical organization. The model assumes that production is a problem solving process based on labor and knowledge. A CEO's knowledge is a resource of limited supply for the firm, because the CEO has a limited amount of time. The location of an establishment determines the costs of accessing CEO knowledge. We show how adjustments to the hierarchical organization can help mitigate these costs.

Specifically, we consider a model with two production locations. The wages in the local labor markets may differ between locations. Firms compete monopolistically in a single product market facing heterogeneous tastes for their product. Production requires labor and knowledge. Both inputs are costly because employees are remunerated for their time and knowledge (as in Caliendo and Rossi-Hansberg, 2012; Garicano, 2000). Each firm has one CEO at the headquarters in one of the two locations that constitutes the highest management layer of the firm. The CEO determines the firm organization: he decides whether to produce in the headquarters establishment or a subordinate establishment at the other location or both and determines the number of hierarchical layers per establishment. If he chooses to have two establishments, he allocates his time and the production quantities to the establishments. The CEO hires production workers at the lowest and middle managers at potential higher hierarchical layers of the firm. Finally, he determines his knowledge as well as the knowledge of the employees. The CEO makes these choices in order to efficiently use his and the employees' time and knowledge.

The production workers input labor and solve problems covered by their knowledge. The managers and the CEO spend their time communicating and solving the unresolved problems that are sent successively from the production workers through potential middle management layers to the CEO. The communication costs are higher if communication takes place between the subordinate establishment and the headquarters. We assume that the managers know everything that the production workers know and more. The CEO is consequently the most

knowledgeable employee of the firm. He faces a trade-off: producing in a subordinate establishment may provide access to lower wages, but at the expense of higher communication costs with the employees there.

We derive the following results about the optimal firm organization. First, as in Caliendo and Rossi-Hansberg (2012), adding a management layer decreases the marginal production costs for single-establishment firms because it allows the firm to reduce the knowledge of the production workers. It entails a quasi-fixed cost because the firm pays intermediate managers that do not supply labor in production. Consequently, only single-establishment firms above a minimum size threshold add a layer.

Second, multi-establishment firms add a layer at a smaller size than single-establishment firms, but only at one of their establishments. If they add a layer at only one establishment, fewer managers need to be hired because only part of the total quantity is produced there. This possibility thus reduces the quasi-fixed costs of the additional layer. Importantly, adding a layer at one establishment decreases the marginal costs of production at *both* establishments. The management layer releases CEO time. The CEO uses this time for the other establishment, thereby reducing its marginal production costs. In consequence, the CEO of a multi-establishment firm adds a layer at one establishment at a smaller size and at the other establishment at a larger firm size than if the firm were single-establishment. In consequence, the optimal hierarchical organization of the establishments is interdependent.

Third, the communication friction between the subordinate establishment and the headquarters affects the optimal choices in the firm. Given the number of layers, the optimal amount of knowledge of the production workers and possible managers at the subordinate establishment increases with the communication costs to avoid the higher communication costs between the employees and the CEO at the headquarters. Likewise, the knowledge level of the production workers at the headquarters increases with the communication costs between the headquarters and the subordinate establishment, though to a lesser extent. The knowledge increase at the subordinate establishment does not fully compensate the communication friction, so the CEO needs to spend more of his time for the subordinate establishment. In response, he increases the knowledge of the employees also at the headquarters. The higher communication costs with the subordinate establishment and the consequently higher knowledge of its employees imply that it is more valuable to add the layer, and reduce the knowledge of the employees, at the subordinate establishment.

These model predictions are consistent with with the higher number of layers at multi-establishment firms documented in the data. They also map into the gradual reorganization of multi-establishment firms and, due to the interdependence of establishment organization, explain why headquarters of multi-establishment firms have a lower number of layers than headquarters of same-size single-establishment firms.

By elucidating the connection of a firm's number of establishments and its optimal hierarchical organization, the paper contributes to the understanding of the determinants of firm performance. There is very little empirical evidence on the questions whether firms copy the

hierarchical structure of existing establishments when founding new ones, or whether adding an establishment has repercussions on the organization of the existing employees. We show that firm organization offers a fruitful perspective to understand the productivity differences between establishments of multi-establishment firms uncovered in Charnoz et al. (2015), Giroud (2013) and Kalnins and Lafontaine (2013). These papers show that proximity to the headquarters empirically increases establishment investments, productivity and longevity.

Our results also speak to the management literature. Bloom et al. (2016) document that half of the total variation in management practices between different U.S. establishments is due to variation between establishments within the same firm, even though better management practices lead to higher productivity of these establishments. They argue that larger firms may find it harder to align management practices across establishments (p. 10). Our paper offers a novel perspective on their result. Heterogeneous management practices in multi-establishment firms may reflect asymmetries in the optimal hierarchical organization of employees across establishments. Implementing managerial practices requires managerial time. Asymmetries in the optimal number of hierarchical layers and the optimal amount of CEO time allocated to each establishment may manifest in heterogeneous managerial practices.

To develop our model, we build on the literature of firms as knowledge hierarchies (see Garicano and Rossi-Hansberg, 2015, for an overview; Garicano, 2000). A series of papers documents that firms add management layers as they grow, and that adding layers helps them maintain their productivity (Caliendo and Rossi-Hansberg, 2012; Caliendo et al., 2015a, b; Friedrich, 2016; Spanos, 2016).[1] Our paper shows that not only the size of a firm, but also its geography in terms of its number of establishments is an important determinant of the hierarchical organization of employees. To date, this aspect has been largely neglected, even though multi-establishment firms are among the largest firms in developed economies and account for a substantial share of aggregate employment.[2]

Our insights are relevant beyond multi-establishment firms, for example for the study of multinational firms. Standard models, in particular models of horizontal foreign investment, implicitly assume that firms copy their existing operations (e.g., Helpman et al., 2004; Antràs and Yeaple, 2014, for a survey). A better understanding of the implications of spatial growth for the organization of employees in firms helps reconcile these theories with the limited portability of parent productivity to foreign affiliates in the data (e.g. Antràs and Yeaple, 2014; Irarrazabal et al., 2013; Tintelnot, 2017).

The paper is structured as follows. The next section describes the data that we use and contains the summary statistics. Section 3 presents the facts on multi-establishment firm organization. Section 4 develops the baseline model of firm organization to explain these findings, and section 5 discusses possible model extensions. Section 6 concludes.

[1] In the broader literature on the hierarchical organization of firms, Rajan and Wulf (2006) and Guadalupe and Wulf (2010) study the organization of management positions in 300 large publicly traded U.S. firms. Chen (2017) develops a model of firms as monitoring hierarchies in industry equilibrium, building inter alia on Calvo and Wellisz (1978) and Qian (1994).

[2] Gumpert (2015) contains a knowledge hierarchy model where firms produce at more than one location, but with a fixed number of layers. Crèmer et al. (2007) study firm language in a setting with multiple divisions.

2 Data and descriptive statistics

We construct a detailed linked firm-establishment-employee data set for Germany. The data cover the period 1998-2014. They contain information on the legal form, sales, and value added of firms, and the location at the county level, three digit sector, and age of each establishment. We observe all employees of the establishments subject to social security contributions as of 30 June every year. For each employee, the data include information on the age, gender, education, occupation, employment history and wages. Each employee, establishment and firm has a unique identifier, so we can follow the different units of observation over time. The establishment identifier may change when the establishment changes ownership from one firm to another. We have access to a complimentary data set that allows following the establishments nonetheless. The employee identifiers never change, even if the employee changes the employer.

We assemble the data set from two sources. The universe of Social Security records provides the data on employees and establishments. We use the establishment history panel, the employee history and the extension file entry and exit. The ORBIS database of Bureau van Dijk contains balance sheet information of firms. We merge the Social Security records and the ORBIS database using record linkage techniques. Our algorithm exploits the regulation that the establishment names in the Social Security data have to contain the firm name. We identify the headquarters (HQ) establishment of a firm as the establishment with the same zip code or locality as the firm.[3] Appendix A.1 contains background information on the components of our data set and describes the record linkage procedure in detail. Consistent with the literature, we restrict our sample to full-time employees (e.g., Card et al., 2013; Dustmann et al., 2009).

The data set is an unbalanced panel. We use the 2012 cross section for cross-sectional analyses, because it contains the maximum number of establishments. The panel analyses use the periods 1998-2010 and 2012-2014. We exclude the year 2011 because of changes in the occupational classification in that year (for details, see Appendix A.2). We restrict the sample to firms with at least 10 employees in at least one year. 99% of the firms dropped due to this requirement are small single-establishment firms.

Table 1 provides descriptive statistics that compare single-establishment (SE) and multi-establishment (ME) firms in the 2012 cross section. Appendix Tables A.1 and A.2 show that the sample characteristics are similar in the 1998-2010 and 2012-2014 panels.

Our sample comprises around 144 thousand establishments that belong to 109 thousand firms and employ 6.4 million individuals. The data cover 22 percent of total employment subject to social security contributions in Germany in June 2012 and almost one third of total full time employment in 2012 (Bundesagentur für Arbeit, 2016).[4] We do not observe sales and value added for all firms, but only the larger firms due to limitations of the ORBIS data. Though only 9 percent of all firms in our sample are multi-establishment firms, 31 percent of establishments belong to and 34 percent of employees work for them. The sample covers all

[3]The Social Security records contain the address of each establishment and the ORBIS database contains the address of the firm. We use this information for the linkage, but for confidentiality, we are only allowed to use the county of each establishment in our analyses.

[4]The total number of full time employees is only available for December 2012.

Table 1: Descriptive statistics, SE vs. ME firms, 2012 cross section

Units of observation	N	Share ME firms						
Firms	109,348	.090						
with non-missing sales	54,035	.094						
with non-missing value added	19,152	.180						
Establishments	144,428	.310						
Employees	6,355,914	.340						
Descriptive statistics	N	ME	Mean	SD	p25	p50	p75	p95
# employees per firm	99,524	0	42	92	13	21	39	133
	9,824	1	222	1979	22	50	127	650
Sales per firm (M €)	48,976	0	29	750	2	4	9	73
	5,059	1	350	4,238	4	17	79	573
Value added per firm (M €)	15,713	0	17	207	3	6	11	43
	3,439	1	121	1,595	5	10	26	157

sectors. The share of multi-establishment firms is 7.5 percent in manufacturing, the largest broad sectoral category, and 12 percent in retail and service respectively.

As the descriptive statistics show, multi-establishment firms are substantially larger than single-establishment firms in terms of their employees, sales and value added. The median multi-establishment firm employs more than double as many employees as the median single-establishment firm; at the 95th percentile, the difference is even fivefold. Likewise, the sales and the value added of multi-establishment firms exceed those of single-establishment firms.

Table 2 provides more detailed evidence on the group of multi-establishment firms. The top panel documents the heterogeneity among them. While more than half of multi-establishment firms have two establishments, the largest five percent have 10 establishments or more. Most multi-establishment firms are active in only one three-digit sector. Even at the higher end of the distribution, the number of sectors is significantly lower than the number of establishments. The size of the establishments of multi-establishment firms varies with a substantially larger standard deviation than the one for single-establishment firms, which results because the size cut-off is not binding at the establishment level for multi-establishment firms. Half of all multi-establishment firms do not have establishments that are farther than 39 km from their headquarters. At the top of the distribution, the distance exceeds 540 km, which is about two thirds of the maximum possible distance within Germany. The distribution of the area covered by multi-establishment firms is similarly skewed.

The lower panel of the table provides more details on the investment patterns of multi-establishment firms. We regress a dummy variable that is equal to one if a firm maintains a subordinate establishment in a county on firm and county characteristics, including the distance of the county to the firm headquarters. We find that larger multi-establishment firms are more likely to own subordinate establishments. A larger market potential increases the probability of investment, consistent with market-seeking motives. Lower wages and land prices in the county relative to the headquarters also increase the probability of investment, which points to cost-cutting motives of investment. It is important to control for population in a county

Table 2: Descriptive statistics, ME firms, 2012 cross section

Descriptive statistics	N	Mean	SD	p50	p75	p95
# establishments per ME firm	9,824	4.6	19.6	2	3	10
# sectors per ME firm	9,824	1.6	0.9	1	2	3
# employees per establishment	44,904	48	430	8	24	156
Maximum distance to HQ	9,824	218	189	39	167	546
Minimum area covered	3,584	30,075	41,712	6,933	49,717	124,564

Investment probability	$\Pr(y_{ij}=1)=\Phi(\beta_0+\beta_1\mathbf{x}_i+\beta_2\mathbf{x}_j)$, with i firm, j county					
Log number of employees	0.225^{***}		0.220^{***}		0.228^{***}	
	(0.013)		(0.011)		(0.012)	
Log sales		0.145^{***}		0.142^{***}		0.147^{***}
		(0.009)		(0.009)		(0.009)
Log market potential	0.066^{***}	0.070^{***}	0.094^{***}	0.100^{***}	0.053^{***}	0.062^{**}
	(0.018)	(0.029)	(0.016)	(0.026)	(0.024)	(0.032)
Log population					0.417^{***}	0.411^{***}
					(0.017)	(0.016)
Relative wages	-0.126	-0.158	-0.228^{*}	-0.296^{+}	-0.250^{*}	-0.325^{+}
	(0.110)	(0.160)	(0.109)	(0.154)	(0.118)	(0.166)
Relative land prices			0.020^{***}	0.021^{***}	-0.007^{***}	-0.006^{+}
			(0.003)	(0.003)	(0.003)	(0.003)
Log distance to HQ	-0.320^{***}	-0.280^{***}	-0.320^{***}	-0.281^{***}	-0.313^{***}	-0.269^{***}
	(0.016)	(0.017)	(0.018)	(0.017)	(0.018)	(0.018)
Constant	-2.571^{***}	-3.253^{***}	-2.731^{***}	-3.570^{***}	-7.128^{***}	-7.984^{***}
	(0.363)	(0.510)	(0.303)	(0.482)	(0.501)	(0.616)
HQ sector dummies	Y	Y	Y	Y	Y	Y
Legal form dummies	Y	Y	Y	Y	Y	Y
Number of observations	4,573,405	2,357,880	3,969,702	2,057,544	3,969,702	2,057,544

Standard errors are clustered at HQ-county-level and shown in parentheses. $^{+}$ $p<0.10$, * $p<0.05$, ** $p<0.01$, *** $p<0.001$. The sample includes only multi-establishment firms and is filled at the firm-county level. *Dependent variable:* dummy variable that is equal to one if firm i has a subordinate establishment in county j. *Independent variables: Log number of employees:* log number of employees of firm i; *Log sales:* log sales of firm i; *Log market potential:* distance weighted average of the GDP of county j and surrounding counties; *Log population:* population of county j; *Relative wages/land prices:* wages/land prices in county j relative to wages in county of headquarters of firm i; *Log distance:* log distance between county j and county of headquarters of firm i in km. Wages are calculated as average wages in a county excluding the respective firm.

to uncover the negative effect of relative land prices. Finally, we find that firms are the less likely to invest in a county, the more distant the county is from the headquarters. This result indicates that geographic frictions between the headquarters and a county hinder investment.

3 Evidence on the hierarchical organization of multi-establishment firms

This section describes differences in the hierarchical organization between single-establishment and multi-establishment firms in the cross-section and over time. To measure the hierarchical organization, we assign employees to layers based on their occupation reported in the Social

Security data. We build on the classification of Caliendo et al. (2015b) and distinguish four levels of layers:

Level	Designation	Occupations
3	CEO	CEOs, managing directors
2	Intermediate managers	Senior experts, middle managers
1	Supervisors	Supervisors, engineers, technicians, professionals
0	Production workers	Clerks, operators, production workers

Caliendo et al. (2015b)'s mapping uses the French PCS-ESE classification of occupations. We transfer their assignment to the German classification of occupations using official correspondence tables, analogous to the procedure of Friedrich (2016) for Danish data. Appendix B.1 provides details on our procedure and a list of occupations by level. Appendix B.2 uses additional survey data to show that the tasks and job characteristics of occupations are similar within each layer, but systematically different across layers in ways that plausibly reflect differences between the roles within firms of employees at different layers.

3.1 The hierarchical organization of single vs. multi-establishment firms

We first explore differences in the hierarchical organization at the firm level by comparing the number of management layers per firm in the cross-section. We treat the layer at the lowest level in each firm as non-managerial and count the number of layers above it. The lowest layer consists of employees at level 0 in 89 percent of firms.

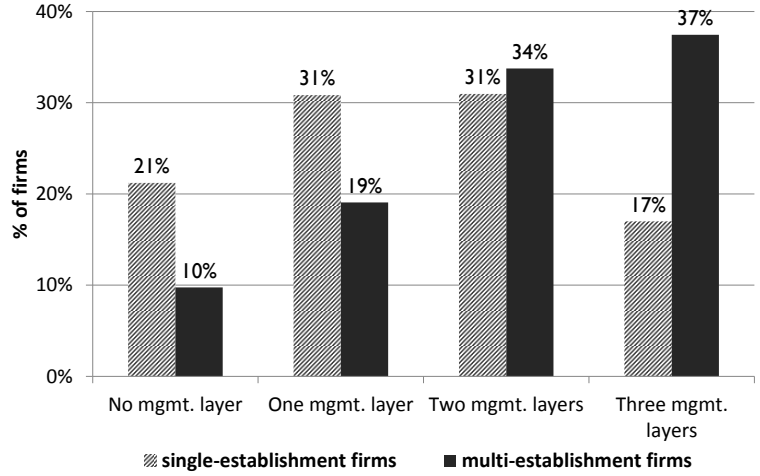
On average, firms have 1.49 management layers with a standard deviation of around 1 in the 2012 cross-section. Multi-establishment firms are more hierarchical than single-establishment firms: the average number of management layers in ME firms is 1.99 and higher than the average number of 1.44 in SE firms.

Figure 1 plots the number of management layers by firm type. The distribution is very dissimilar between SE and ME firms. The distribution has an inverse U-shape for SE firms. A third of SE firms have one or two management layers respectively. 21 percent have no management layer, and less than one fifth have three management layers. In contrast, more than two thirds of ME firms have two or three management layers. Only ten percent do not have a management layer and 19 percent have one management layer.[5]

While the differences in Figure 1 may be driven by a firm's number of establishments, they may likewise result from the differences in size between SE and ME firms documented in Table 1 or other firm characteristics. Table 3 presents the results of Poisson regressions that condition

[5]There are two reasons why some firms do not have management layers. First, social security data only contain information on employees that pay social security contributions. Owner-managers are therefore only included if they pay themselves a wage. Our results are robust to excluding owner-managed firms (see Appendix Table B.2). Second, the data contain only one occupation per employee. Managers of small firms may be attributed a production occupation if they execute such an occupation for most of their time.

Figure 1: Number of management layers by firm type, 2012 cross-section.



The figure plots the distribution of the number of layers separately for SE and ME firms. The sample consists of the 2012 cross-section and only includes firms with at least ten employees. More than 80% of firms have consecutive layers. Appendix B.3 contains a table of the share of firms with consecutive layers by firm type and number of layers.

on size as determinant of the number of management layers and take differences in the sector, legal form and location of firms into account. Specifically, we estimate

$$\#\,\text{management layers}_i = \exp\left(\beta_0 + \beta_1\, D_{\text{ME firm},i} + \beta_2\, \text{size}_i + \alpha_l + \alpha_n + \alpha_s\right), \tag{1}$$

where i refers to the firm, l to its legal form, n to the county of the headquarters, s to the headquarter sector, $D_{\text{ME firm},i}$ is a equal to one for ME firms and zero otherwise, and α denotes fixed effects. As the mean and variance of the number of management layers are approximately equal, the Poisson model is a reasonable approximation of the data.

Through all specifications, multi-establishment firms have a significantly higher number of layers than single-establishment firms. The coefficients in column 1 imply that multi-establishment firms have 15.5 percent more management layers than single-establishment firms. The effect is equivalent to a doubling of the number of non-managerial employees. As column 2 shows, the multi-establishment firm dummy does not only reflect a non-linear size effect. The effect is smaller, but still positive and significant when we control for sales in columns 3 and 4. The decreases in effect sizes is partly due to the non-random availability of the sales data. The ORBIS contains sales information only for the larger firms in the sample, so the variation in the number of layers in this group is lower.[6] To explore further potential sources of omitted variables bias, we exclude multi-establishment firms with establishments in different sectors, or subordinate establishments in the headquarter county in columns 5 and 6 and find very similar effect sizes. Column 7 excludes large multi-establishment firms with more employees than the 95th percentile of single-establishment firms to make sure that the effects are not driven by

[6]The standard deviation of the number of layers for multi-establishment (single-establishment) firms with sales is .71 (.79), which is lower than the value of .98 (1) for those without.

Table 3: Regression results, number of management layers, 2012 cross-section

# mgmt. layers, Poisson	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$D_{\text{ME firm}}$	0.144***	0.111***	0.061***	0.063***	0.135***	0.141***	0.149***
	(0.006)	(0.006)	(0.007)	(0.007)	(0.008)	(0.006)	(0.006)
Log # non-managerial employees	0.143***	−0.050***		−0.005	0.150***	0.144***	0.148***
	(0.002)	(0.011)		(0.003)	(0.002)	(0.002)	(0.002)
Log # non-managerial employees, squared		0.029***					
		(0.002)					
Log sales			0.179***	0.182***			
			(0.002)	(0.003)			
HQ sector dummies	Y	Y	Y	Y	Y	Y	Y
HQ county dummies	Y	Y	Y	Y	Y	Y	Y
Legal form dummies	Y	Y	Y	Y	Y	Y	Y
# firms	105,948	105,948	53,566	53,566	101,160	103,694	105,547
Sample	Full	Full	Full	Full	Same sector	Diff. county	Size $\leq p_{SE}(95)$

2012 cross-section, only firms with at least 10 employees. Robust standard errors in parentheses. $^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. *Dependent variable:* number of management layers. *Independent variables:* $D_{ME\ firm}$: 1 if firm is ME firm, 0 otherwise; *Log # non-managerial employees:* log number of employees at lowest layer of the firm; *Log sales:* log sales of the firm. Constant included. Column 5 excludes multi-establishment firms that have at least one subordinate establishments in a different three-digit sector than the headquarters. Column 6 excludes multi-establishment firms with subordinate establishments in the headquarters' county. Column 7 excludes firms that have more employees than the 95th percentile of single-establishment firms.

outliers. The estimated coefficients are very similar. Appendix Tables B.2 and B.3 replicate the cross-section regression results separately by legal form and for the 1998-2010 panel.

Fact 1 summarizes our findings:

Fact 1. *Multi-establishment firms have more management layers than single-establishment firms of the same size, the same legal form, in the same county and the same sector.*

3.2 Hierarchical organization and firm geography

To explore whether the hierarchical organization of multi-establishment and single-establishment firms of the same size differs because multi-establishment firms group their employees into different establishments, or because the establishments are in geographically distinct locations, we study whether differences in the geographic expansion of firms affect their hierarchical organization. We restrict the sample to multi-establishment firms and re-estimate equation (1) taking into account geography:

$$\#\,\text{management layers}_i = \exp\left(\beta_0 + \beta_1 \text{geography}_i + \beta_2 \text{size}_i + \alpha_l + \alpha_n + \alpha_s\right), \tag{2}$$

where i now refers to the multi-establishment firm. We employ two measures of firm geography, the maximum log distance in kilometers between a subordinate establishment and the headquarters, and the minimum area in square kilometers covered by all establishments. Distance is defined for all multi-establishment firms, whereas the area is only defined for firms with at least

Table 4: Regression results, number of management layers in ME firms and geography, 2012 cross-section

# mgmt. layers, Poisson	(1)	(2)	(3)	(4)	(5)	(6)
Maximum log distance to HQ	0.021***	0.011***				
	(0.003)	(0.004)				
$D_{\text{2nd quartile of maximum log distance}}$			0.011			
			(0.015)			
$D_{\text{3rd quartile of maximum log distance}}$			0.069***			
			(0.014)			
$D_{\text{4th quartile of maximum log distance}}$			0.106***			
			(0.015)			
Log area spanned by firm				0.012***	0.010***	
				(0.002)	(0.003)	
$D_{\text{2nd quartile of log area}}$						0.045+
						(0.023)
$D_{\text{3rd quartile of log area}}$						0.108***
						(0.023)
$D_{\text{4th quartile of log area}}$						0.146***
						(0.024)
Log # non-managerial employees	0.115***		0.113***	0.090***		0.088***
	(0.003)		(0.003)	(0.005)		(0.005)
Log sales		0.115***			0.090***	
		(0.004)			(0.005)	
HQ sector dummies	Y	Y	Y	Y	Y	Y
HQ county dummies	Y	Y	Y	Y	Y	Y
Legal form dummies	Y	Y	Y	Y	Y	Y
# firms	9,287	5,039	9,287	3,320	1,984	3,320

2012 cross-section, only firms with at least 10 employees. Columns 1-3 include all ME firms, columns 4-6 only ME firms with at least two subordinate establishments. Robust standard errors in parentheses. + p < 0.10, * p < 0.05, ** p < 0.01, *** p < 0.001. *Dependent variable:* number of management layers. *Independent variables: Maximum log distance to headquarters*: maximum distance between subordinate establishment and headquarters in km; *Area*: minimum area covered by establishments in square kilometers; others see Table 3.

two subordinate establishments. We take the maximum distance of the subordinate establishments to the headquarters if the firm has more than one subordinate establishment; using the mean distance yields similar results. Firm size controls both for the positive effect of size on the number of layers and for the possibility of larger firms investing at farther destinations.

Table 4 presents the regression results for the 2012 cross-section. The regression results show that both distance and area have a positive impact on the number of management layers in a firm. According to column 1, a ten percent increase in the maximum distance of an establishment to the headquarters leads to a 0.2 percent increase in the number of layers. The magnitude of the effect is about a fifth of the elasticity of the number of layers with respect to the number of non-managerial employees. The effect is robust to using sales as size measure in column 2. The impact of the log area in columns 4 and 5 is similar. Columns 3 and 6 include dummies for the quartiles of the maximum log distance and log area distribution, respectively. The coefficients show that the impact of distance and area increases monotonically and is strongest for those firms with the largest spatial expansion. Appendix Table B.4 replicates the

cross-section result for the 1998-2010 panel of multi-establishment firms.

We summarize our findings:

Fact 2. *The number of management layers of multi-establishment firms increases with the distance to their subordinate establishments and the area their establishments cover, conditional on firm size, legal form, their headquarters' county and sector.*

3.3 Transitional dynamics of the hierarchical organization

The cross-sectional differences between multi-establishment and single-establishment firms indicate that the dynamics of adding and dropping a layer likely differ across the two groups of firms. Table 5 displays the shares of firms that transition from a number of managerial layers in period t to a possibly different number of managerial layers in period $t+1$. Interestingly, the propensity of firms to reorganize is quite similar across the two groups. The hierarchical structure is sluggish: at least four fifth of firms in both groups keep their number of managerial layers across periods. In case that firms change the number of layers, they typically add or drop exactly one layer. At most one percent of firms add or drop more than one layer.

The transitional dynamics at the firm level may disguise adjustments at the establishment level in multi-establishment firms. In fact, the hierarchical organization of subordinate establishments is rarely a copy of the one in the headquarters: in more than 40 percent of all multi-establishment firms, the number of managerial layers at the headquarters exceeds the number of layers at all subordinate establishments (for details on the differences in the number of layers between establishments, see Appendix B.3). Even if the number of layers is similar, the level of management often differs.

Table 6 therefore digs deeper into the organization of multi-establishment firms and considers their dynamics at the establishment level. To summarize the hierarchical organization of multi-establishment firms with a possibly different number of establishments, the table counts the number of managerial layers at the headquarters and the maximum number of managerial layers at the subordinate establishment.

Two features are notable. First, the hierarchical organization at the establishment level is less stable than the hierarchical organization at the firm level: there is less mass on the diagonal of Table 6 than on the diagonal of the right panel of Table 5. The establishment-level hierarchical organization of multi-establishment firms is also less stable than the organization of single-establishment firms. Second, multi-establishment firms reorganize gradually and add or drop layers at one establishment at a time. For example, among multi-establishment firms with two layers both at the headquarters and the subordinate establishments, 9 percent add a layer at the headquarters and 10 percent drop a layer at the subordinate establishments, but less than 1 percent of firms choose a lower or higher number of layers across all establishments. The latter adjustment does not show up as reorganization at the firm level.

The gradual adjustment of the hierarchical structure indicates that the positive impact of multi-establishment firm status on the number of managerial layers of Fact 1 reflects a more hierarchical organization only at some, but not necessarily across all of their establishments.

Table 5: Transitional dynamics of the hierarchical structure at the firm level, by firm type

# layers	SE firms						ME firms					
in t/t+1	# firms	0	1	2	3	exit	# firms	0	1	2	3	exit
0	536,958	90.9	7.1	0.6	0.1	1.2	24,035	90.9	8.2	0.7	0.0	0.2
1	424,580	7.8	84.6	6.6	0.4	0.6	31,216	7.7	83.3	8.1	0.6	0.2
2	207,705	1.0	11.6	80.7	6.4	0.4	26,425	0.9	9.7	81.4	7.9	0.1
3	97,211	0.2	1.1	11.1	87.2	0.3	27,744	0.1	0.6	6.8	92.4	0.2

The table displays the percentage of firms that reorganize from a number of managerial layers in period t (given in the rows) to a possibly different number of managerial layers in period $t+1$ (given in the columns), separately for SE and ME firms. Sample: 1998-2010 panel of firms with at least 10 employees in at least one year.

Table 6: Transitional dynamics of the hierarchial structure at establishment level, ME firms

Organization in $t/t+1$	0, 0	1, <1	1, 1	2, <2	2, 2	3, <3	3, 3	# ME firms
HQ 0, SubE. 0	83.1	4.4						23,531
HQ 1, SubE. <1	7.5	72.2	4.4	5.6				13,799
HQ 1, SubE. 1		4.9	74.2	6.6				12,787
HQ 2, SubE. <2		4.4	4.7	74.1	2.5	6.2		16,230
HQ 2, SubE. 2				9.9	68.0	8.9		4,374
HQ 3, SubE. <3				5.3	2.1	83.7	2.7	16,357
HQ 3, SubE. 3						8.7	86.5	5,579

The table displays the percentage shares of firms that change from a hierarchical structure in period t displayed in the rows to the hierarchical structure in period $t+1$ displayed in the columns. The first figure denotes the number of managerial layers of the headquarters. The second figure denotes the maximum number of managerial layers at the subordinate establishments. For easier readability, the cells are empty if they contain less than 1% of firms. Sample: 1998-2010 panel of firms with at least 10 employees in at least one year.

In order to understand whether multi-establishment firms are more likely to reorganize headquarters or subordinate establishments, Table 7 re-estimates equation (1) using the number of management layers of the headquarters as dependent variable:

$$\#\,\text{management layers at HQ}_{it} = \exp\left(\beta_0 + \beta_1\, D_{\text{ME firm},it} + \beta_2\, \text{size}_{it} + \alpha_l + \alpha_n + \alpha_s + \alpha_t\right). \quad (3)$$

The regression compares the hierarchical structure of the headquarters of multi-establishment and single-establishment firms.

The regression results show that the headquarters establishments of multi-establishment firms tend to have a lower number of managerial layers than single-establishment firms given firm size. This finding holds both in the cross-sectional model in column 1 and with firm fixed effects in column 2. Column 3 includes an interaction term of firm status and size. The results show that the positive effect of size on the number of layers is mitigated for the headquarters of multi-establishment firms.

Overall, we conclude:

Fact 3. *Multi-establishment firms reorganize gradually and add or drop layers at one establishment at a time. While the number of managerial layers at the firm level in multi-establishment firms exceeds the number of layers in single-establishment firms, multi-establishment firms reorganize the headquarters only at a larger size than single-establishment firms.*

Table 7: Regression results, number of management layers at headquarters, single vs. multi-establishment firms, 1998-2010 panel

# mgmt. layers at headquarters, Poisson	(1)	(2)	(3)
$D_{\text{ME firm}}$	-0.093^{***}	-0.097^{***}	0.228^{***}
	(0.004)	(0.006)	(0.011)
Log # non-managerial employees	0.321^{***}	0.275^{***}	0.336^{***}
	(0.001)	(0.002)	(0.001)
$D_{\text{ME firm}} \times$			-0.079^{***}
Log # non-managerial employees			(0.003)
Year dummies	Y	Y	Y
HQ sector dummies	Y	N	Y
HQ county dummies	Y	N	Y
Legal form dummies	Y	N	Y
Firm fixed effects	N	Y	N
# observations	747,338	1,150,120	747,338

1998-2010 panel, only firms with at least 10 employees in at least one year. Robust standard errors in parentheses. $^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. *Dependent variable:* number of management layers at firm headquarters. *Independent variables:* see Table 3. Constant included.

4 A model of the hierarchical organization of multi-establishment firms in a single goods market

To explain why the number of establishments of a firm affects the hierarchical organization, we develop a model of the organization of employees in multiple establishments. In the model, we allow firms to endogenously choose both the number of establishments and the hierarchical organization to understand the interplay of the two choices. While empirically both market access motives and production efficiency motives play a role in the decision to open establishments (see Table 2), we abstract from market access considerations in this section to transparently study the impact of firm organization on production efficiency. We extend the model to separate goods markets in the next section.

4.1 Set-up

We consider an economy with two locations, $j = \{0, 1\}$. There are N_j agents in location j, each of which is endowed with one unit of time. The agents are immobile, so labor markets are separate with local wages $w_0 \geq w_1$. Output is perfectly mobile and sold on a single goods market.

Establishing firms. The agents decide whether they would like to become an entrepreneur and establish a firm, or offer their time in the labor market. If an agent chooses to become an entrepreneur, he pays a sunk cost of establishing a headquarters at his location of f^e units of labor. He receives the blueprint of a differentiated product i and the exogenous taste for the product α_i. The taste draws α_i follow a known distribution $G(\alpha_i)$. They affect how much

utility consumers derive from consuming product i:

$$U(x(\alpha_i)) = \left(\int_A \alpha_i^{\frac{1}{\sigma}} x(\alpha_i)^{\frac{\sigma-1}{\sigma}} M dG(\alpha) \right)^{\frac{\sigma}{\sigma-1}}. \tag{4}$$

$x(\alpha_i)$ is a consumer's consumption of product i, A is the set of all available products and M is the mass of firms. After observing the taste, the entrepreneur decides whether to pay the fixed costs of production f and become the CEO of a firm, or supply his time in the labor market.

To simplify the exposition, sections 4.2 and 4.3 analyzes a single CEO with taste draw α in location 0. Section 4.4 studies the competition among many firms i with heterogeneous taste draws α_i in the goods market.

Producing output. Production is a problem solving process based on labor and knowledge (as in Caliendo and Rossi-Hansberg, 2012; Garicano, 2000). Every unit of labor employed in production generates a unit mass of problems. Problems are production possibilities: the labor input turns into output if the problems are solved using knowledge. Mathematically, knowledge is an interval ranging from zero to an upper bound. We denote the length of a knowledge interval by z. The CEO and his employees solve a problem if it is realized within their knowledge interval. The problems follow a distribution with the exponential density $f(z) = \lambda e^{-\lambda z}$, where $z \in [0, \infty)$ refers to the domain of possible problems and λ defines the predictability of the production process. Combining n units of labor and knowledge $\bar{z}$ yields

$$q = n\left(1 - e^{-\lambda \bar{z}}\right)$$

units of output, where $1 - e^{-\lambda \bar{z}}$ is the value of the cumulative distribution function.

Learning and communicating. The CEO hires employees to input labor and knowledge in the production process. Employees put in labor by spending their time generating problems. The employees have to learn the knowledge to be used in production. They spend $w_j cz$ to learn a knowledge interval of length z, where c denotes the learning cost that is equal across locations. The CEO remunerates the employees for their time and their learning expenses, so employees receive remuneration $w_j(1 + cz)$.

The employees can communicate unsolved problems, so they can leverage differences in their knowledge. Communication is costly because the receiver of the unsolved problems in location j spends θ_{kj} units of time listening to problems communicated by employees in location k. We assume that communication across space is more costly than communication within the same location. The CEO therefore spends a larger amount of time listening to problems sent from employees in location 1 than from those in location 0: $1 > \theta_{10} \geq \theta_{00} > 0$. The communication costs are symmetric, i.e. $\theta_{10} = \theta_{01}, \theta_{11} = \theta_{00}$. If an employee does not know the solution to a problem, he cannot tell who knows, but has to search for a competent fellow employee.

Organizing employees. The CEO organizes the employees of the firm in order to minimize the production costs. The optimization problem consists of several elements. First, the CEO decides whether to produce in one establishment at either location or two establishments at both locations, and determines the optimal number of layers for each establishment. We use the term "organizational structure" and the variable ω to denote the number of establishments and number of layers per establishment of a firm. All other endogenous variables depend on the location of an establishment and the organizational structure, so we index them by j, ω. Given the organizational structure, the CEO chooses an optimal level of his knowledge $\bar{z}_{0,\omega}$. If there are two establishments, the CEO also chooses how much output $q_{j,\omega}$ to produce and which share $s_{j,\omega}$ of his time to spend at each establishment. Finally, the CEO determines the optimal number $n^{\ell}_{j,\omega}$ and knowledge level $z^{\ell}_{j,\omega}$ of the employees in each layer ℓ and establishment j.

We call the employees at the lowest layer $\ell = 0$ production workers. They put in labor and some knowledge in the production process. We call the employees at the higher layers $\ell \geq 1$ managers. They spend their time communicating unsolved problems from the employees at the next lower layer and input only knowledge in the production process. The highest managerial layer consists of the CEO. The knowledge levels of the employees are overlapping, so employees at layer ℓ know the knowledge of employees at layer $\ell - 1$ and more. Consequently, the CEO delimits the maximum possible output per unit of labor input by choosing his knowledge $\bar{z}_{0,\omega}$, because the CEO is the most knowledgeable employee of the firm. As the density of problems is decreasing in z, the knowledge of the production workers covers the solution to the most common problems, whereas higher layers also know the solutions to problems that occur more rarely. This minimizes the probability that costly communication is necessary.[7]

The communication costs θ_{jk}, the learning costs c, the predictability of the production process λ and the fixed costs f are exogenous parameters. The model is partial equilibrium, so the wages w_j are also taken as given. We take total output $\tilde{q}$ as given in subsections 4.2 and 4.3, but endogenize it in subsection 4.4 based on the exogenous taste draw α.

4.2 The cost minimization problem

The variable of interest with view to the facts uncovered in section 3 is the organizational structure ω: the number of establishments and the number of hierarchical layers per establishment. The organizational structure affects the other choice variables, so the resulting optimization problem is complex. To render it tractable, we divide it into three parts.

First, we consider the choice of the organizational structure. The CEO chooses the optimal organizational structure ω to minimize the total production costs given the total output $\tilde{q}$.

$$C\left(\tilde{q}\right) = \min_{\omega \in \Omega} \tilde{C}_{0,\omega}\left(\tilde{q}\right) \tag{5}$$

Second, we consider firm level choices for a given organizational structure. At the firm level,

[7] Garicano (2000) shows that an optimal knowledge hierarchy features specialization and organization by frequency, i.e. only the lowest layer inputs labor and the knowledge of higher layers covers the rarer problems.

the CEO determines which share of his time $s_{j,\omega}$ to allocate to each establishment, how much output $q_{j,\omega}$ to produce at each establishment, and how much knowledge $\bar{z}_{0,\omega}$ to learn in order to minimize the production costs of the chosen organizational structure. The production costs consist of the production costs at each establishment j and the remuneration of the CEO time that is not used in establishment production.

$$\tilde{C}_{0,\omega}(\tilde{q}) = \min_{\{q_{j,\omega},s_{j,\omega}\}_{j=0}^{1},\bar{z}_{0,\omega}\geq 0} \sum_{j=0}^{1} C_{j,\omega}(q_{j,\omega}, s_{j,\omega}, \bar{z}_{0,\omega}) + \left[1 - \sum_{j=0}^{1} s_{j,\omega}\right] w_0 (1 + c\bar{z}_{0,\omega}) \tag{6}$$

$$\text{s.t.} \quad s_{0,\omega} + s_{1,\omega} \leq 1 \tag{7}$$

$$q_{0,\omega} + q_{1,\omega} \geq \tilde{q} \tag{8}$$

Constraint (7) describes that the CEO has only one unit of time. The production quantities have to sum up at least to the total output $\tilde{q}$, as constraint (8) shows.

Third, given the firm level choices, we consider the establishment level choices. The CEO decides on the number of employees and their knowledge for each layer and establishment. If the CEO decides to produce a positive amount of output at an establishment, the production costs consist of the number of employees per layer and their remuneration as well as the remuneration of the CEO for the time that he spends on the establishment. Otherwise, the production costs at the establishment are zero.

$$C_{j,\omega}(q_{j,\omega}, s_{j,\omega}, \bar{z}_{0,\omega}) = \begin{cases} \min\limits_{\{n_{j,\omega}^{\ell}, z_{j,\omega}^{\ell}\}_{\ell=0}^{L_j}\geq 0} \sum\limits_{\ell=0}^{L_j} n_{j,\omega}^{\ell} w_j \left(1 + c z_{j,\omega}^{\ell}\right) + s_{j,\omega} w_0 (1 + c\bar{z}_{0,\omega}) & \\ & \text{if } q_{j,\omega} > 0 \\ 0 & \text{if } q_{j,\omega} = 0 \end{cases} \tag{9}$$

$$\text{s.t.} \quad n_{j,\omega}^{0}\left(1 - e^{-\lambda \bar{z}_{0,\omega}}\right) \geq q_{j,\omega} \tag{10}$$

$$s_{j,\omega} \geq n_{j,\omega}^{0} \theta_{j0} e^{-\lambda z_{j,\omega}^{L_j}} \tag{11}$$

$$n_{j,\omega}^{\ell} \geq n_{j,\omega}^{0} \theta_{jj} e^{-\lambda z_{j,\omega}^{\ell-1}} \quad \forall \ell = 1, ..., L_j \tag{12}$$

$$\bar{z}_{0,\omega} \geq z_{j,\omega}^{L_j} \tag{13}$$

$$z_{j,\omega}^{\ell} \geq z_{j,\omega}^{\ell-1} > 0 \quad \forall \ell = 1, ..., L_j \tag{14}$$

L_j denotes the number of layers of management at the establishment below the CEO.

Constraint (10) implies that the CEO has to hire enough production workers to produce the desired amount of output given his knowledge. According to constraints (11) and (12), the CEO has to hire a sufficient number of managers at each layer such that they can listen to all problems communicated to them, and faces a similar constraint on his time. The number of problems communicated to a higher layer is computed as the number of problems, $n_{j,\omega}^{0}$, multiplied with the communication costs, θ_{jj} or θ_{j0}, and the probability that the problem is not yet solved, $e^{-\lambda z_{j,\omega}^{\ell-1}}$. Finally, knowledge levels are overlapping and positive (constraints 13, 14).

4.3 The optimal organization of employees

We solve the problem by backward induction. We determine the number of employees and their knowledge per layer and establishment in section 4.3.1, taking as given the firm level choices as well as the organizational structure. We solve for the knowledge of the CEO, the allocation of his time and of output given the organizational structure in section 4.3.2. This allows deriving the impact of the total production quantity $\tilde{q}$ and other parameters on the endogenous choices for every organizational structure in section 4.3.3. The CEO chooses the organizational structure with the minimum production costs taking into account the repercussions of his decision for the firm and establishment choices, as we explain in section 4.3.4.

The text focuses on the results and their intuition. Appendix C.1 contains the derivations.

4.3.1 Establishment-level choices: The number and knowledge of employees

The establishment level outcomes depend on the choices at the firm level—CEO knowledge, the allocation of output and CEO time—through the binding constraints (10)-(12).

Constraint (10) determines the number of production workers. Constraint (11) fixes the knowledge level of the highest layer at the establishment. The level has to be high enough such that the establishment uses only the allocated share of CEO time given the number of production workers:

$$e^{\lambda z_{j,\omega}^{L_j}} = \frac{q_{j,\omega}}{1 - e^{-\lambda \bar{z}_{0,\omega}}} \frac{\theta_{j0}}{s_{j,\omega}}.$$

The first order conditions imply that the knowledge levels of the production workers and managers at lower layers are a recursive function of the knowledge level at the highest layer:

$$\begin{aligned} e^{\lambda\left(z_{j,\omega}^{\ell-1} - z_{j,\omega}^{\ell-2}\right)} &= \left(1 + c z_{j,\omega}^{\ell}\right)\lambda \quad \forall \ell = 2, ..., L_j, \\ e^{\lambda z_{j,\omega}^{0}} &= \left(1 + c z_{j,\omega}^{1}\right)\lambda \theta_{jj}. \end{aligned}$$

Constraint (12) determines the number of intermediate managers as a function of the number of production workers and knowledge levels.Finally, the marginal production costs $\xi_{j,\omega}$ and the marginal benefit of CEO time $\varphi_{j,\omega}$ are given by:

$$\begin{aligned} \xi_{j,\omega} &= \frac{w_j \left(1 + c z_{j,\omega}^{0} + \frac{1}{\lambda} + \mathbb{1}(L_j \geq 1) \frac{\theta_{00}}{\lambda} \sum_{\ell=1}^{L_j} e^{-\lambda z_{j,\omega}^{\ell-1}}\right)}{1 - e^{-\lambda \bar{z}_{0,\omega}}}, \\ \varphi_{j,\omega} &= \frac{w_j c}{\lambda \theta_{j0}} \theta_{00} e^{\lambda\left(z_{j,\omega}^{L_j} - z_{j,\omega}^{L_j - 1}\right)} \quad \text{for } L_j > 0, \quad \varphi_{j,\omega} = \frac{w_j c}{\lambda \theta_{j0}} e^{\lambda z_{j,\omega}^{0}} \quad \text{for } L_j = 0. \end{aligned}$$

4.3.2 Firm-level choices: CEO knowledge, allocation of CEO time and output

Concerning firm level choices, whether or not the CEO produces at two establishments, he balances the marginal benefit and marginal cost of his knowledge:

$$w_0 c_0 = \frac{\lambda e^{-\lambda \bar{z}_{0,\omega}}}{1 - e^{-\lambda \bar{z}_{0,\omega}}} \sum_{j=0}^{1} \xi_{j,\omega} q_{j,\omega} \tag{15}$$

The marginal costs consist of the marginal increase of CEO remuneration $w_0 c_0$. The marginal benefit is the reduction of production costs, because more output is producible for every unit of labor input with higher CEO knowledge.

The CEO optimally uses his full unit of time and produces only the required quantity, i.e. the constraints (7) and (8) are binding in optimum. If the CEO chooses to produce at two establishments, the CEO can reduce the production costs by reallocating the production quantity or his time, respectively, as long as the marginal costs of production or the marginal benefit of CEO time are not equalized.

Proposition 1. *Suppose the firm produces at two establishments. The CEO allocates output to equate the marginal production costs across establishments, and his unit of time to equate the marginal benefit of CEO time across establishments. Formally, in optimum,*

$$\xi_{0,\omega} = \xi_{1,\omega} \quad \textit{and} \tag{16}$$

$$\varphi_{0,\omega} = \varphi_{1,\omega}. \tag{17}$$

Proof. See Appendix C.1.2. □

Hence, the CEO produces the total quantity in one establishment if the endogenous marginal costs of total output at this establishment are lower than the marginal costs at the other establishment, and spends his full unit of time for one establishment if the endogenous marginal benefit of doing so exceeds the marginal benefit of spending time for the other establishment. This result implies that multi-establishment production is not optimal under certain conditions.

Corollary 1. *It is not optimal to produce at two establishments with the same number of below-CEO management layers $L_0 = L_1$ if the communication costs across space exceed those within a location, $\theta_{10} > \theta_{00}$, but the wages are equal or higher at the subordinate location than at the headquarters location, $w_1 \geq w_0$.*

Proof. See Appendix C.1.2. □

The marginal cost of production do not depend on the communication cost across space θ_{10}. Hence, equation (16) implies that the below-CEO knowledge levels are equal in two establishments with the same number of layers given symmetric wages. The marginal benefit of CEO time depends on θ_{10}, so equation (17) requires that the below-CEO knowledge levels differ across the two establishments. It is not possible to fulfill both equations at the same time, so the CEO will not choose to produce at both establishments.

4.3.3 Comparative statics

The establishment and firm-level results allow characterizing the impact of the total production quantity $\tilde{q}$ and the communication costs θ_{10} on the choice variables of the CEO for every organizational structure ω. The results for the production quantity in a single-establishment firm are in line with the results derived for a knowledge hierarchy with non-overlapping knowledge levels and limited CEO time in Caliendo and Rossi-Hansberg (2012):

Proposition 2. *Suppose the firm produces at one establishment. Given the number of layers of management L of the establishment, and using the notation $\omega = L$,*

a) the number of employees at all layers $n_{j,L}^{\ell}$, $\forall \ell < L$ and the knowledge of the employees at all layers $z_{j,L}^{\ell}$, $\forall \ell < L$ increase with the production quantity $\tilde{q}$, and

b) the knowledge of the CEO $\bar{z}_{0,L}$, the marginal benefit of CEO time $\varphi_{j,L}$ and the marginal production cost $\xi_{j,L}$ increases with the production quantity $\tilde{q}$.

c) The cost function $C_{0,L}(\tilde{q})$ is strictly increasing with the production quantity $\tilde{q}$. The average cost function $AC_{0,L}(\tilde{q})$ is convex in the production quantity $\tilde{q}$. It reaches a minimum at $\tilde{q}_L^*$ where it intersects with the marginal cost function, and converges to infinity for $\tilde{q} \to 0$ and $\tilde{q} \to \infty$.

Proof. See Appendix C.1.3. □

Intuitively, the number of production workers $n_{j,L}^0$ and the CEO knowledge $\bar{z}_{0,L}$ increase because labor and knowledge are complementary inputs in production, so the CEO optimally employs a higher amount of both to achieve higher output. An increase in the number of production workers leads to an increase in the number of employees $n_{j,L}^{\ell}$ at every below-CEO layer. As the time of the CEO is limited, the knowledge of the employees at the highest below-CEO layer $z_{j,L}^{L-1}$ increases to ensure that all problems can be communicated. As the lower-layer knowledge levels are recursive functions of higher-layer knowledge, the knowledge at lower layers $z_{j,L}^{\ell}$, $\ell = 0, ..., L-2$ increases, though to a lesser extent, thereby mitigating the increase in the number of employees at layers $\ell = 1, ..., L-1$.

The marginal benefit of CEO time increases because as the firm grows, the limitations to CEO time become more and more costly, as reflected in the increase of the knowledge of the employees at the highest layer below the CEO $z_{j,L}^{L-1}$. The marginal production costs increase because higher levels of knowledge at all layers increase the production costs.

The resulting cost function is strictly increasing, as the marginal costs are positive. The average cost function is U-shaped. The U-shape reflects two counteracting forces. On the one hand, the marginal cost of production increase with the production quantity. On the other hand, the quasi-fixed costs of the CEO and the intermediate managers are spread over a larger production quantity. For quantities below the minimum efficient scale $\tilde{q} < \tilde{q}_L^*$, the latter effect dominates, for quantities above $\tilde{q} > \tilde{q}_L^*$, the former effect dominates. In other words, for quantities below the minimum efficient scale, the CEO has more time available than needed—every additional unit of output decreases the average costs. For quantities above the minimum efficient scale, the CEO is time constrained and additional units of time would increase efficiency.

Proposition 3. *Suppose the firm produces at two establishments. Suppose further that there is some asymmetry between the establishments, i.e. either $\theta_{10} > \theta_{00}$, or $w_1 \neq w_0$, or $L_1 \neq L_0$. Given the combination of hierarchical layers at the two establishments ω,*

a) the total number of production workers $\sum_{j=0}^{1} n_{j,\omega}^{0}$ *increases with the production quantity* $\tilde{q}$*, while the knowledge of the employees at all below-CEO layers* $z_{j,\omega}^{\ell}$ *is constant,*

b) the knowledge of the CEO $\bar{z}_{0,\omega}$ *increases, the marginal benefit of CEO time* $\varphi_{j,\omega}$ *does not vary, and the marginal production cost* $\xi_{j,\omega}$ *decreases with the production quantity* $\tilde{q}$*,*

c) The cost function $C_{0,\omega}(\tilde{q})$ *is strictly increasing with the production quantity* $\tilde{q}$*. The average cost function* $AC_{0,\omega}(\tilde{q})$ *decreases with the production quantity* $\tilde{q}$*.*

In case of full symmetry, i.e. if $\theta_{10} = \theta_{00}$*,* $w_1 = w_0$ *and* $L_1 = L_0$*, the production quantity has the same effect on the multi-establishment firm as on a single-establishment firm.*

Proof. See Appendix C.1.3. □

As in a single-establishment firm, a higher production quantity $\tilde{q}$ leads to a higher total number of production workers and a higher CEO knowledge because labor and knowledge are complementary inputs in production.

The impact of a higher quantity on the other endogenous variables is quite different as long as there is some asymmetry between establishments that may stem from differences in location characteristics, asymmetric numbers of layers or both. The key driver behind the differences is that producing at both establishments allows firms to leverage the asymmetries across locations. Intuitively, the CEO optimally combines the asymmetric establishments by allocating his time and the production quantity and thus achieves a lower production costs. The optimal establishment organization fulfills equations (16) and (17), i.e. it ensures that the marginal production costs and the marginal benefit of CEO time are equal across establishments. Equations (16) and (17) thus jointly determine the optimal knowledge levels, and as neither equation depends on the production quantity, the knowledge levels do not vary with the production quantity either. As the marginal benefit of CEO time only depends on the below-CEO knowledge levels, it is consequently constant. In contrast, higher CEO knowledge decreases the marginal cost of production, which therefore decrease with the production quantity.

The marginal production costs are positive throughout, so the cost function increases with the production quantity. The average production costs are decreasing. This property results from the possibility to combine establishments having a different number of layers, or operating under different communication costs or wages in a multi-establishment firm, together with the positive impact of a higher quantity on CEO knowledge. For example, the CEO may choose to employ production workers at one establishment and production workers and one layer of intermediate managers at the other establishment. The CEO is optimally allocates the production quantity and his time to the establishments. For quantities between the minimum efficient scales of an organization with only one and two layers, the combination of the two organizational structures leads to lower average costs due to the U-shape of the average cost functions. This finding itself does not imply that the average costs are decreasing. As the below-CEO knowledge levels are constant, the average costs could be constant. The decrease

results because the CEO's knowledge increases with higher quantity. In consequence, more output is producible for every unit of labor input, which leads to the decrease of average costs.

If the two establishments are fully symmetric with respect to both location characteristics and the number of layers, the multi-establishment firm is equivalent to a two-location single-establishment firm. Consequently, changes in the total production quantity affect the multi-establishment firm in the way stated in Proposition 2 for single-establishment firms.

In addition to the production quantity, changes in the communication friction $\theta_{10} > \theta_{00}$ between the subordinate establishment and the headquarters affect the organizational structure.

Proposition 4. *Suppose the firm produces at two establishments. Suppose further that* $\theta_{10} > \theta_{00}$*. Given the combination of hierarchical layers at the two establishments* ω*,*

a) the total number of production workers $\sum_{j=0}^{1} n_{j,\omega}^{0}$ *decreases with the communication costs* θ_{10}*, while the knowledge of the employees at all below-CEO layers* $z_{j,\omega}^{\ell}$ *increases, and*

b) the knowledge of the CEO $\bar{z}_{0,\omega}$*, the marginal benefit of CEO time* $\varphi_{j,\omega}$*, and the marginal production cost* $\xi_{j,\omega}$ *increase with the communication costs* θ_{10}*.*

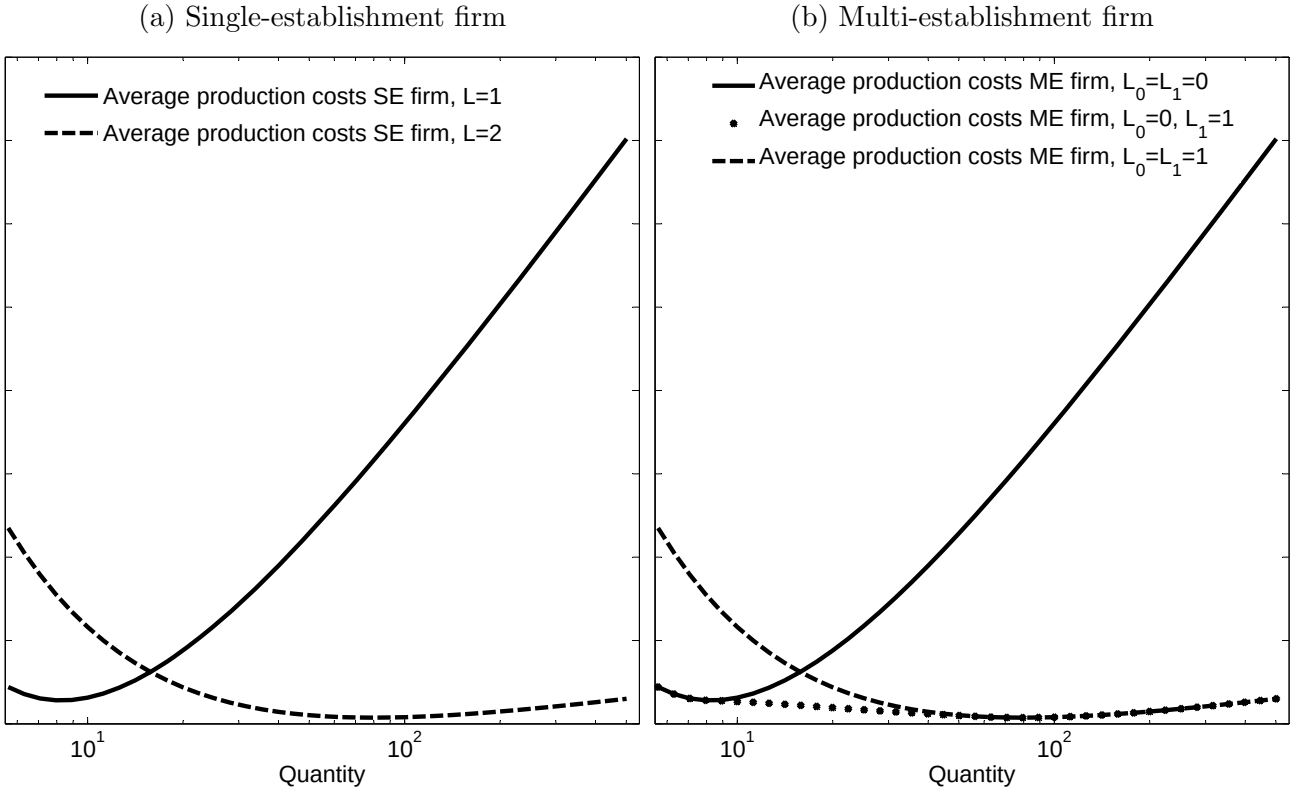
The increase of the below-CEO knowledge levels with the communication costs θ_{10} *is stronger at higher than at lower layers, and stronger at the subordinate than at the headquarters establishment.*

Proof. See Appendix C.1.3. □

An increase in the communication costs θ_{10} implies that it is more costly to use the CEO's knowledge. That is, generating problems is more costly, because they may have to be communicated to the CEO to produce output. In consequence, the CEO hires fewer production workers to generate fewer problems. To nevertheless produce the required amount of output, the CEO adjusts the optimal levels of knowledge. The CEO increases the knowledge at the below-CEO levels because of his time constraint: with higher communication costs, more problems have to be solved by the below-CEO layers. The CEO increases his own knowledge to maintain the production quantity despite the lower number of production possibilities as fewer problems are generated by the workers. These adjustments lead to higher marginal costs, and a higher marginal benefit of CEO time. The increase of knowledge is stronger at higher layers because the number of employees is lower at higher layers, so it is cheaper to increase their knowledge.

Proposition 4 illustrates an important feature of multi-establishment organization: changes of parameters that affect one establishment lead to organizational adjustments at both establishments, because the organization of the two establishments is interdependent. In case of the communication costs, higher communication costs θ_{10} imply that accessing CEO knowledge is more expensive for employees in location $j = 1$. Their knowledge therefore increases, so they communicate fewer problems. As the problem probability distribution function is downward sloping, the marginal product of knowledge in terms of additional output is decreasing. The CEO therefore optimally compensates for the additional communication costs by not only increasing the knowledge at the subordinate establishment, but also at the headquarters. The

Figure 2: Illustration of the average cost functions



requirement to equate both marginal production costs and marginal benefit of CEO time implies that the increase is higher at the subordinate establishment than at the headquarters.

4.3.4 The optimal organizational structure

Equation (5) implies that CEO chooses the organizational structure with the minimal costs. The results of sections 4.3.1-4.3.3 are the basis for characterizing the resulting average cost function.

To simplify the exposition, we first consider the optimal organization when both locations are fully symmetric, i.e. both wages and communication costs are equal: $w_0 = w_1$ and $\theta_{10} = \theta_{00}$. If the CEO did not have the option to organize employees in several establishments, the average cost function would be similar to the function characterized in Caliendo and Rossi-Hansberg (2012, Proposition 2). Given the number of hierarchical layers, the average cost function is U-shaped, as shown in Proposition 2. The minimum average cost for a given number of layers decreases and the level of output that achieves this minimum $\tilde{q}_L^*$ increases with the number of layers. The average cost curves of an organization with L and $L+1$ layers cross in the interval $(\tilde{q}_L^*, \tilde{q}_{L+1}^*)$, and the CEO optimally adds a layer of management at the crossing (for a formal derivation, see Appendix C.1.4). In the following, we denote the crossing $\tilde{q}_L^{L+1}$. Figure 2a illustrates the average cots function of a single-establishment firm with only a CEO ($L = 1$) or a CEO and intermediate managers ($L = 2$).

As stated in Proposition 3, the average cost function of the multi-establishment firm coincides with the average cost function of a single-establishment firm if the organization has a symmetric number of below-CEO layers. Otherwise, the average costs are decreasing. It is

therefore decisive to determine for which quantities the CEO chooses symmetric and asymmetric numbers of layers across establishments. We will use the variable L_j to denote the number of below-CEO layers at establishment j and the variable $L = \max_j\{L_j\} + 1$ to denote the number of layers of the firm including the CEO in the following.

Proposition 5. *Suppose the firm produces at two establishments. The average costs of an asymmetric organization with L_j below-CEO layers at establishment j and $L_j + 1$ below-CEO layers at establishment $k \neq j$ are lower than the minimum average cost of a symmetric organization with L_j below-CEO layers at both establishments for quantities above the minimum efficient scale $\tilde{q} > \tilde{q}_L^*$. The average cost function of a symmetric organization with L_j+1 below-CEO layers at both establishments intersects the average cost function of the asymmetric organization at a higher quantity than the quantity at which it intersects the average cost functions of the symmetric organizations with L_j below-CEO layers $\tilde{q}_L^{L+1}$. The CEO of a multi-establishment firm therefore adds a layer of management at one establishment at the minimum efficient scale $\tilde{q}_L^*$ and a layer of management at the other establishment at a quantity in the interval $(\tilde{q}_L^{L+1}, \tilde{q}_{L+1}^*)$.*

Proof. See Appendix C.1.4. □

Proposition 5 implies that multi-establishment firms reorganize gradually. They do not add a layer at all establishments at size $\tilde{q}_L^{L+1}$, at which single-establishment firms reorganize. Instead, they add a layer at only one establishment at a smaller size $\tilde{q} < \tilde{q}_L^{L+1}$, and add the layer at the other establishment only at a larger size $\tilde{q} > \tilde{q}_L^{L+1}$.

The driver behind these results is the limited amount of CEO time. Intuitively, for quantities between the minimum efficient scales $\tilde{q} \in (\tilde{q}_L^*, \tilde{q}_{L+1}^*)$, the average production costs of a symmetric organization with L_j below-CEO layers increase due to the limited CEO time, as explained for the single-establishment firm with L layers in Proposition 2. At the same time, the firm is not large enough to efficiently use the additional layer of management of a symmetric organization with $L_j + 1$ below-CEO layers for $\tilde{q} < \tilde{q}_L^{L+1}$. The asymmetric multi-establishment organization with L_j and $L_j + 1$ below-CEO layers combines the two organizational structures and allows optimally allocating CEO time and the production quantity among the two. The additional layer of managers hired at the establishment with L_j+1 below-CEO layers releases time that the CEO uses for the establishment with L_j below-CEO layers, thus alleviating the time constraint. At the same time, the number of managers is scalable by allocating the production quantity. For small quantities close to $\tilde{q}_L^*$, the CEO produces most of the quantity at the establishment with L_j below-CEO layers and correspondingly only hires few managers. The larger the quantity is, the higher is the amount of output produced and thus the higher is the number of managers hired at the establishment with L_j+1 below-CEO layers. Due to this flexibility, the asymmetric organization leads to lower average costs than the minimum average production costs of the symmetric organization with L_j below-CEO layers. In consequence, adding the layer at the other establishment is optimal only for quantities larger than $\tilde{q}_L^{L+1}$.

Formally, the average cost function of a symmetric organization with L_j below-CEO layers increases for quantities above the minimum efficient scale, whereas the average cost function

of the asymmetric organization decreases. Consequently, the former intersects the decreasing average cost function of a symmetric organization with $L_j + 1$ below-CEO layers at a lower quantity than the latter.

Figure 2b illustrates the average costs of a multi-establishment firm. As there is full symmetry, the average cost function of a multi-establishment firm and a single-establishment firm with only production workers below the CEO coincide ($L_0 = L_1 = 0$), as do the cost functions of a multi-establishment firm with workers and intermediate managers at both establishments ($L_0 = L_1 = 1$) and a single-establishment firm with workers, intermediate managers and the CEO. In contrast, an asymmetric multi-establishment organization with only production workers at one and workers and intermediate managers at the other establishment ($L_0 = 0, L_1 = 1$) leads to lower average production costs for a range of quantities between the minimum efficient scales of the organizations with a symmetric number of below-CEO layers. The resulting reorganization implies that multi-establishment firms have a higher number of layers than single-establishment firms, that they reorganize gradually, and that their establishment organization is interdependent.[8]

Asymmetric communication costs or wages modify these results, but they do not alter them fundamentally. If there is a friction to the communication across space, but wages are symmetric, i.e. if $\theta_{10} > \theta_{00}$ and $w_1 = w_0$, multi-establishment production is only worthwhile with an asymmetric number of below-CEO layers, as stated in Corollary 1. The average production costs increase with the communication costs θ_{10}, so the range of quantities for which multi-establishment production is efficient is lower than with symmetric communication costs. Lower wages at location 1, $w_1 < w_0$, counterbalance higher communication costs across space and decrease the average production costs. If $w_1 < w_0$, both a multi-establishment organization with a symmetric number of below-CEO layers, and an organization with the CEO in location 0 and all production in location 1 may be optimal, depending on the size of the firm.

4.4 The profit maximization problem and the optimal quantity

As we now understand how the optimal organizational structure and thus the production costs depend on the production quantity, it is possible to endogenize it. To do so, it is necessary to take the demand on the goods market into account. Consumers maximize their utility (4) subject to the constraint that the value of their consumption must not exceed their wage income. An individual consumer in location j demands of product i the quantity $x(\alpha_i) = \alpha_i w_j P^{\sigma-1} p(x(\alpha_i))^{-\sigma}$. The total demand results from multiplying the individual demand by the number of agents per location N_j, $q(\alpha_i) = \alpha_i (R_0 + R_1) P^{\sigma-1} p(x(\alpha_i))^{-\sigma}$. $R_j = N_j w_j$ denotes income per location and P is the price index. We normalize the price index to 1.

[8]The average costs of an asymmetric organization coincide with the average costs of the symmetric multi-establishment organizations for quantities below and above their minimum efficient scales respectively, because in these ranges, single-establishment production is more efficient than asymmetric multi-establishment production.

Each CEO chooses the optimal output to maximize firm profits given the taste draw:

$$\max_{\tilde{q}\geq 0} \pi_i(\alpha_i) = p(\tilde{q}(\alpha_i))\tilde{q}(\alpha_i) - C(\tilde{q}) \tag{18}$$

Substituting the demand function and solving for the optimal output yields

$$\tilde{q}(\alpha_i) = \alpha_i \left(R_0 + R_1\right) \left(\frac{\sigma}{\sigma - 1}\xi_{0,\omega}\left(\tilde{q}(\alpha_i)\right)\right)^{-\sigma}, \tag{19}$$

where we make explicit that the marginal costs $\xi_{0,\omega}$ are a function of α_i through output. The optimal price is a constant mark-up over marginal costs:

$$p(\alpha_i) = \frac{\sigma}{\sigma - 1}\xi_{0,\omega}\left(\tilde{q}(\alpha_i)\right) \tag{20}$$

The taste parameter determines whether a firm is large or small.

Proposition 6. *The optimal output $\tilde{q}(\alpha_i)$ increases continuously with the taste parameter α_i.*

Proof. See Appendix C.1. □

This result implies that the optimal organization of firms is jointly determined by the parameters θ_{jk}, w_j, c, and λ, as well as the taste for the firm's product α_i. The CEo produces if the profits exceed the fixed production costs f.

5 Hierarchical organization of multi-establishment firms with market access considerations

Tba. [This section will elaborate more on how the model matches Fact 2.]

6 Conclusion

This paper provides insights on a new margin of firm organization: the interplay of the number of establishments and firms' hierarchical organization, and its consequences for production efficiency. Multi-establishment firms are major players in today's complex and increasingly globalized economy, so their study remains an exciting area for future research.

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