Productivity and Organization in Portuguese Firms*

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Abstract

The productivity of firms is, at least partly, determined by a firm's actions and decisions. One of these decisions involves the organization of production in terms of the number of hierarchical layers of management the firm decides to employ. Using detailed employer-employee matched data and firm production quantity and input data for Portuguese firms, we study the endogenous response of quantity-based and revenue-based productivity to firm reorganizations measured by changes in the number of management layers. We show that as a result of an exogenous demand or productivity shock that makes the firm reorganize and add a management layer, quantity-based productivity increases by about 6%, while revenue-based productivity drops by around 3%. Such a reorganization makes the firm more productive, but also increases the quantity produced to an extent that lowers the price charged by the firm and, as a result, its revenue-based productivity.

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1 Introduction

A firm's productivity depends on the way it organizes production. The decisions of its owners and managers on how to combine different inputs and factors of production with particular technologies, given demand for their product, determine the production efficiency of the firm. Clearly, these decision makers face many constraints and random disturbances. Random innovations or disruptions, regulatory uncertainties, changes in tastes and fads, among many other idiosyncratic shocks, are undoubtedly partly responsible for fluctuations in firm productivity. However, these random –and perhaps exogenous– productivity or demand fluctuations also result in firm responses that change the way production is organized, thereby affecting its measured productivity. For example, a sudden increase in demand due to a product becoming fashionable can lead a firm to expand and add either a plant, a more complex management structure, a new division, or a new building. These investments are lumpy and, as such, will change the firm's production efficiency and prices discontinuously as well.

In this paper we study the changes in productivity observed in Portuguese firms when they reorganize their management structure by adding or dropping layers of management. Consider a firm that wants to expand as a result of a positive demand shock and decides to add a layer of management (say add another division and a CEO that manages the whole firm). The new organization is suitable for a larger firm and lowers the average cost of the firm thereby increasing its quantity-based productivity. Moreover, the switch to an organizational structure fitted for a larger firm also reduces the marginal cost of the firm leading to higher quantities and lower prices. Because organizational decisions are lumpy, at the moment of the switch, the firm will probably have an organizational structure that is still a bit large for its size. The implication is that changes in organization that add organizational capacity in the form of a new management layer, lead to increases in quantity-based productivity, but also reductions in revenue-based productivity through reductions in prices. Hence, the endogenous response of firm productivity to exogenous shocks that trigger reorganizations can be complex and differ depending on the measure of productivity used.

Using a recently developed measure of changes in organization we show that these patterns are very much present in the Portuguese data. To illustrate the parallel case when a firm receives a negative shock, consider the example of a Portuguese firm producing "Knitted and crocheted pullovers, cardigans, and similar articles". This firm downsized heavily between 2002 and 2005 as a result of China's entry into the WTO and the resulting reduction in quotas and increased import competition. We observe that the quantity sold by the firm declines by 50%, but its price increases by 35%. The firm reduced its layers of management by firing several managers and employees performing secondary tasks, and focusing on its main expertise by maintaining its "sewers and embroiderers". Overall, its labor forced declines by 27 employees. Using the measures of productivity we explain in detail below, the result is a reduction in quantity-based productivity of 53% combined with an increase in revenue-based productivity of 10.3%. The experience and behavior of this firm is by no means unique. Using many examples and a host of empirical measures, we show that reorganization and productivity are systematically linked in the way we describe.

Although the logic above applies to many types of organizational changes and other lumpy investments, we explain it in more detail using a knowledge-based hierarchy model that can guide us in our empirical implementation. Furthermore, this model provides an easy way to empirically identify changes in organization using occupational classifications. The theory of knowledge-based hierarchies was developed in Rosen (1982), Garicano (2000) and, in an equilibrium context with heterogeneous firms, in Garicano and Rossi-Hansberg (2006) and Caliendo and Rossi-Hansberg (2012, from now on CRH). In particular, we use the model in CRH since it provides an application of this theory to an economy with firms that face heterogeneous productivity and demands for their products. In the context of CRH, we provide novel theoretical results that characterize the pattern of quantity-based and revenue-based productivity when firms reorganize as a result of exogenous demand or productivity shocks.

The basic technology is one that requires time and knowledge. Workers use their time to produce and generate 'problems' or production possibilities. Output requires solving this problems. Workers have knowledge that they use to try to solve these problems. If they know how to solve them, they do, and output is realized. Otherwise they can redirect the problem to a manager one layer above. Such a manager tries to solve the problem and, if it cannot, can redirect the problem to an even higher-level manager. The organizational problem of the firm is to determine how much does each employee know, how many of them to employ, and how many layers of management to use in production.

Using matched employer-employee data for the French manufacturing sector, Caliendo, Monte and Rossi-Hansberg (2015), from now on CMRH, show how to use occupation data to identify the layers of management in a firm.[1] They show that the theory of knowledge-based hierarchies can rationalize the layer-level changes in the number of employees and wages as firms grow either with or without changing layers. For example, as implied by the theory, a reorganization that adds a layer of management leads to increases in the number of hours employed in each layer but to a *reduction* in the average wage in each preexisting layer. In contrast, when firms grow without reorganizing they add hours of work to each layer and they *increase* the wages of each worker. This evidence shows that when firms expand and contract they actively manage their organization by hiring workers with different characteristics. The Portuguese data exhibits the same patterns that CMRH found for France. Importantly, the detailed input, revenue and quantity data for Portugal allows us to go a step further and measure the productivity implications of changes in organization.

Measuring productivity well is notoriously complicated and the industrial organization literature has proposed a variety of techniques to do so (see Berry, Levinsohn and Pakes, 1995, Olley and Pakes, 1996, Levinsohn and Petrin, 2003, Wooldridge, 2009, De Loecker and Warzinsky, 2012, and Ackerberg et al., 2015, among others). The first issue is whether we want to measure quantity-based or revenue-based productivity. The distinction is crucial since the former measures how effective is a firm in transforming inputs and factors into output, while the latter also measures any price variation, perhaps related to markups, that results from market power. The ability of firms to determine prices due to some level of market power is a reality

[1] Following CMRH several studies have shown that occupational categories can be used to identify layers of management in other datasets. For example, Tåg (2013) uses Swedish data and Friedrich (2015) uses Danish data.

that is hard to abstract from. Particularly when considering changes in scale that make firms move along their demand curve and change their desired prices.

To measure the effect of organizational change on quantity-based productivity we need a methodology that can account for demand, markup, and productivity shocks over time and across firms.[2] We use the methodology proposed by Forlani et al., (2015), which from now on we refer to as MULAMA. This method uses the same cost minimization assumptions as previous methodologies, like De Loecker and Warzinsky (2012), but makes some relatively strong assumptions on the way demand differs across firms in order to allow for correlated demand and productivity disturbances. Furthermore, it is amenable to introducing the organizational structure we described above. Note also that since we focus on changes in quantity-based productivity as a result of a firm reorganization we can sidestep the difficulties in comparing quantity-based productivity across horizontally differentiated products. Using this methodology, and quantity data available in the Portuguese data, we find that adding (dropping) layers is associated with increases (decreases) in quantity-based productivity.[3] In addition, we extend the methodology to structurally estimate revenue-based-productivity and show that adding (dropping) layers is associated with decreases (increases) in revenue-based productivity, particularly when we properly control for past prices and shocks, as suggested by the theory.[4]

Up to this point we have not addressed the issue of causality. The results above only state that adding layers coincides with increases in quantity-based productivity and declines in revenue-based productivity. To the extent that organization, like capital infrastructure, cannot adjust much in the short run in the wake of current period shocks, the above results can be interpreted as causal. We relax this assumption by using a set of instruments represented by demand and cost shocks predicting organizational changes but uncorrelated with current productivity shocks. The MULAMA estimation strategy allows us to measure these past productivity, demand, and markups shocks. We show that our results on both revenue-based and quantity-based productivity remain large and significant.

Finally, we go one step further, and use the quota removals in sub-industries of the "Textile and Apparel" sector, that resulted from China's entry into the WTO, as an instrument for a firm's reorganization. Focusing on this sector allows us to explore the implications of a clearly exogenous negative demand shock on reorganization and productivity. In Section 3 we present a couple of detailed examples of individual firms in this industry where we describe in more detail the way these firms changed their labor force composition and therefore their organization and productivity. In Section 5.4 we use this exogenous demand shock as an instrument for the change in layers and apply our general methodology. We find that the behavior of

[2] See Marschak and Andrews (1944) and Klette and Griliches (1996) for a discussion of the output price bias when calculating productivity.

[3] In Caliendo, et al. (2018), a previous working paper version of this paper, we show that our findings survive a variety of robustness checks and alternative formulations of the productivity process. For example, we can allow for changes in organization to have a permanent or only a contemporaneous impact on quantity-based productivity.

[4] In Caliendo, et al. (2018), we also find, using a host of different measures of revenue productivity (from value-added per worker to Olley and Pakes, 1996, Wooldridge, 2009, and De Loecker and Warzinsky, 2012), that adding layers is related to decreases in revenue-based productivity.

firms as a result of the reduction in quotas is very much in line with the rest of our findings.[5]

In sum, in this paper we show that the organizational structure of firms, as measured by their hierarchical occupational composition, has direct implications on the productivity of firms. As they add organizational layers, their quantity-based productivity increases, although the corresponding expansion decreases their revenue productivity as they reduce prices.[6] This endogenous component of productivity determines, in part, the observed heterogeneity in both revenue and quantity-based productivity across firms. Failure to reorganize in order to grow can, therefore, result in an inability to exploit available productivity improvements. This would imply that firms remain inefficiently small, as has been documented in some developing countries (Hsieh and Klenow, 2014).

The literature on firm organization and productivity is small and only broadly related to fully specified theories. Gibbons and Henderson (2013) and Bloom and van Reenen (2011) provide nice overviews of the findings relating organization or human resource management practices and productivity. Studies that focus on particular industries, like Ichniowski et al (1997), find large effects of certain management practices on productivity, although Bloom and van Reenen (2011) argue that causality is not always credibly established and many results only use cross-sectional data or disappear when using time-series variation. Ichniowski and Shaw (2003) provide a survey of the literature and argue that advances in information technology (IT) and a skilled labor force seem to generate increases in productivity. Caroli and van Reenen (2001) provides perhaps the best example of a study that links organizational change to measures of productivity using detailed firm-level data. Subsequently, Bloom and van Reenen (2011) have credibly established an empirical link between management practices and productivity, as have Lazear and Shaw (2007) from the perspective of ‘personnel economics’. Garicano and Hubbard (2016) studies the role of organization on productivity among law firms and also find large effects. Relative to this literature, we offer a consistent measure of a characteristic of a firm’s organization: the number of layers.[7] Changes in this measure can be interpreted within a fully-fledged theory of the organization of a firm’s labor force. Furthermore, the theory specifies the effects that changes in layers should have on revenue versus quantity-based productivity. Our main contribution in this paper is then to provide a theory-consistent estimation of the effect that this form of organizational change has on revenue and quantity-based productivity for a large fraction of firms in the Portuguese economy.

The rest of this paper is organized as follows. In Section 2 we provide a short recap of the knowledge-hierarchy theory that we use to guide our empirical exploration and describe its implications for productivity.

[5] In a related result, Garcia and Voigtländer (2019) find, among new Chilean exporters, a reduction in revenue-based productivity and an increase in quantity-based productivity. The mechanism and findings in our paper can be used directly to rationalize their findings since exporting amounts to a firm revenue shock.

[6] Our results also relate to the cost pass-through literature given that a reorganization affects cost and, in turn, prices. As a result, in the paper we also calculate the cost-pass through for all firms (what we refer to as the unconditional measure) and for firms that change organization (conditional). We find that the unconditional cost pass-through estimates are similar to the ones in the literature, but that the estimates conditional on firms reorganizing are somewhat larger, as expected.

[7] Rajan and Wulf (2006) and Guadalupe and Wulf (2010) also measure changes over time in management layers and relate them to economic outcomes. They do not, however, link organizational change to structural measures of quantity and revenue-based productivity.

We finish this section with several examples of Portuguese firms that went through a process of reorganization. Section 3 discusses the Portuguese manufacturing data set we use in the paper and presents the basic characteristics of Portuguese production hierarchies. In particular, we show that firms with different numbers of layers are in fact different and that changes in the number of layers are associated with the expected changes in the number of workers and wages at each layer. Section 4 presents the methodology we use to measure quantity-based and revenue-based productivity. Section 5 presents our main empirical specifications and results, as well as our results for revenue and quantity-based productivity using the China textile shock. Section 6 presents a variety of robustness checks and our estimates of aggregate effects. Section 7 concludes. The appendix includes more details on our data set, a description of all Tables and Figures, as well as additional derivations and robustness tests of the results in the main text.

2 A Sketch of a Theory of Organization and its Empirical Implications

The theory of knowledge-based hierarchies, initially proposed by Garicano (2000), has been developed using a variety of alternative assumptions (see Garicano and Rossi-Hansberg, 2015, for a review). Here we discuss the version of the technology with homogenous agents and heterogeneous demand developed in CRH.

So consider firm i in period t that faces a Cobb-Douglas technology

$$Q_{it}\left(O_{it}, M_{it}, K_{it}\right) = A_{it} O_{it}^{\alpha_O} M_{it}^{\alpha_M} K_{it}^{\gamma-\alpha_M-\alpha_O} \tag{1}$$

with quantity-based productivity A_{it}, returns to scale given by γ and where O_{it} denotes the labor input, M_{it} material inputs and K_{it} capital. The parameter $\alpha_O \geq 0$ represents the expenditure share on the labor input, $\alpha_M \geq 0$ on materials and $\gamma - \alpha_M - \alpha_O$ on physical capital. The labor input is produced using the output of a variety of different workers with particular levels of knowledge. The organizational problem is embedded in this input. That is, we interpret the output of the knowledge hierarchy as generating the labor input of the firm. Hence, in the rest of this section we focus on the organizational problem of labor and abstract from capital and materials. We return to the other factors in our estimation of productivity below.

Production of the labor input requires time and knowledge. Agents employed as workers specialize in production, use their unit of time working in the production floor and use their knowledge to deal with any problems they face in production. Each unit of time generates a problem, that, if solved yields one unit of output. Agents employed as managers specialize in problem solving, use h units of time to familiarize themselves with each problem brought by a subordinate, and solve the problems using their available knowledge. Problems are drawn from a distribution $F(z)$ with $F''(z) < 0$. Workers in a firm know how to solve problems in an interval of knowledge $[0, z_L^0]$, where the superindex 0 denotes the layer (0 for workers) and the subindex the total number of management layers in the firm, L. Problems outside this interval, are passed on to managers of layer 1. Hence, if there are n_L^0 workers in the firm, $n_L^1 = hn_L^0\left(1 - F\left(z_L^0\right)\right)$, managers of layer one are needed. In general, managers in layer ℓ learn $\left[Z_L^{\ell-1}, Z_L^{\ell}\right]$ and there are $n_L^\ell = hn_L^0(1 - F(Z_L^{\ell-1}))$ of them, where $Z_L^\ell = \sum_{l=0}^{\ell} z_L^l$. Problems that are not solved by anyone in the firm are discarded. Agents with knowledge z_L^ℓ obtain a wage $w\left(z_L^\ell\right)$ where $w'\left(z_L^\ell\right) > 0$ and $w''\left(z_L^\ell\right) \geq 0$. Market wages simply compensate agents for their cost of acquiring knowledge.

The organizational problem of the firm is to choose the number of workers in each layer, their knowledge and therefore their wages, and the number of layers. Hence, consider a firm that produces a quantity O of the labor input. $C_L\left(O; w\right)$ is the minimum cost of producing a labor input O with an organization with L layers[8] at a prevailing wage schedule $w\left(\cdot\right)$, namely,

$$C_L\left(O; w\right) = \min_{\{n_L^\ell, z_L^\ell\}_{l=0}^L \geq 0} \sum\nolimits_{\ell=0}^{L} n_L^\ell w\left(z_L^\ell\right) \tag{2}$$

subject to

$$O \leq F(Z_L^L) n_L^0, \tag{3}$$
$$n_L^\ell = hn_L^0[1 - F(Z_L^{\ell-1})] \text{ for } L \geq \ell > 0, \tag{4}$$
$$n_L^L = 1. \tag{5}$$

The first constraint just states that total production of the labor input should be larger or equal than O, the second is the time constraint explained above, and the third states that all firms need to be headed by one CEO. The last constraint is important since it implies that small firms cannot have a small fraction of the complex organization of a large firm. We discuss bellow the implications of partially relaxing this constraint. The *variable* cost function is given by

$$C\left(O; w\right) = \min_{L \geq 0} \left\{C_L\left(O; w\right)\right\}.$$

CRH show that the average cost function ($AC\left(O; w\right) = C\left(O; w\right)/O$) that results from this problem exhibits the properties depicted in Figure 1 (which we reproduce from CMRH). Namely, it is U-shaped given the number of layers, with the average cost associated to the minimum efficient scale that declines as the firm adds layers. Each point in the average cost curve in the figure correspond to a particular organizational design. Note that the average cost curve faced by the firm is the lower-envelope of the average cost curves for a given number of layers. The crossings of these curves determine a set of output thresholds (or correspondingly demand thresholds[9]) at which the firms decides to reorganize by changing the number of layers. The overall average cost, including materials and capital, of a firm that is an input price taker will have exactly the same shape (given our specification of the production function in equation (1) under $\gamma = 1$).

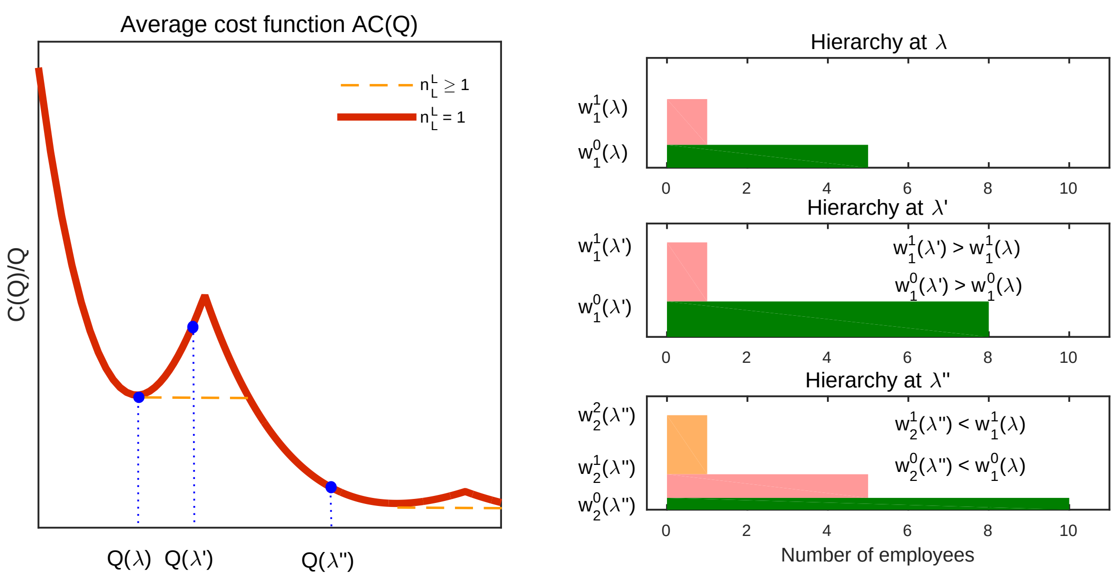
Consider the three dots in the figure, which correspond to firms that face different levels of demand

[8] Throughout we refer to the number of layers of the firm by the number of management layers. So firms with only workers have zero layers, firms with workers and managers have 1 layer, etc.

[9] Note that since output increases (decreases) discontinuously when the firm adds (drops) layers, the average cost curve is discontinuous as a function of the level of demand λ.

as parametrized by λ.[10] Suppose that after solving the corresponding profit maximization using the cost function above, a firm that faces a demand level of λ decides to produce $Q(\lambda)$ (or $q(\lambda)$ in logs). The top panel on the right-hand-side of Figure 1 tells us that it will have one layer with 5 workers and one layer with one manager above them. The figure also indicates the wages of each of them (the height of each bar), which is increasing in their knowledge. Now consider a firm that as a result of a demand shock expands to $Q(\lambda')$ without reorganizing, that is, keeping the same number of layers. The firm expands the number of workers and it increases their knowledge and wages. The reason is that the one manager needs to hire more knowledgeable workers, who ask less often, in order to increase her span of control. In contrast, consider a firm that expands to $Q(\lambda'')$. This firm reorganizes by adding a layer. It also hires more workers at all preexisting layers. However, it hires less knowledgeable workers, at lower wages, in all preexisting layers. The reason is that by adding a new layer the firm can avoid paying multiple times for knowledge that is rarely used by the bottom ranks in the hierarchy. In the next section we show that all these predictions are confirmed by the data.

Figure 1: Average Cost and Organization



We can also use Figure 1 to show how the organizational structure changes as we relax the integer constraint of the top manager, in (5). First, note that at the minimum efficient scale (MES), which is given by the minimum of the average cost, having one manager at the top is optimal for the firm. So the constraint in (5) is not binding. Hence, relaxing the constraint can affect the shape of the average cost function on segments to the right and to the left of the MES. The reason why average costs rise for quantities other than MES is that firms are restricted to have one manager at the top. Otherwise, the firm could expand

[10] In our examples here we focus on changes in the level of demand. Later on we will further consider changes in the exogenous component of productivity and changes in markups. Indeed, whatever pushes the firm to change its desired output can affect a firm's organizational structure.

the optimal organizational structure at the MES by just replicating the hierarchy proportionally as it adds or reduces managers at the top.

For instance, suppose we allow organizations to have more than one manager at the top, namely $n_L^L \geq 1$. Figure 1 presents dashed lines that depict the shape of the average cost for this case. As we can see, the average cost is flat for segments to the right of the MES up to the point in which the firm decides to add a new layer. At the moment of the switch, the average cost starts falling until it reaches the MES and then it becomes flat again. All the predictions that we discussed before still hold for this case. The only difference is the way in which firms expand after they reach their MES up to the point in which they reorganize. We allow for this extra degree of flexibility when we use the structure of the model and take it to the data.[11]

2.1 Productivity Implications - Theory and Data

In the following section we show that firms that grow or shrink substantially do so by adding or dropping management layers. These reorganizations also have consequences on the measured productivity of firms. In the model above quantity-based productivity of a firm in producing the labor input can be measured as the inverse of the average cost at constant factor prices; namely, $Q(\lambda)/\bar{C}(Q(\lambda); C(\cdot; 1), 1, 1)$ where $\bar{C}(Q(\lambda); C(\cdot; w), P_m, r)$ denotes the overall cost function of the firm and P_m and r the price of materials and capital. Note that $Q(\lambda)$ denotes quantity produced and not revenue. Revenue-based productivity is instead given by $P(\lambda) Q(\lambda)/\bar{C}(Q(\lambda); C(\cdot; 1), 1, 1)$ where $P(\lambda)$ denotes the firm's output price.

Quantity-based productivity increases with an increase in λ when the firm adds layers. The reason is simply that any voluntary increase in layers is accompanied by an increase in the quantity produced, which results in a lower average costs for the firm when using the new organizational structure. The firm is only willing to add an extra layer of management, and hire more managers that do not generate production possibilities at a higher cost, if it can use the new organization to produce more at a lower average and marginal cost. Of course, under standard assumptions that lead to a downward sloping demand, the increase in quantity will also decrease the price that consumers are willing to pay for the good. Note that, since the firm is choosing the level of λ at which it switches layers, we know that profits will be continuous in λ. This implies that the increase in revenue has to be identical to the increase in variable costs. Given that, in the presence of fixed production costs, total revenue has to be larger that variable costs in order for profits to be non-negative, the proportional increase in revenue will be smaller than the proportional increase in costs. The result is a decline in revenue-based productivity.

The logic above uses the following assumptions which are necessary for the proof of Proposition 1 below.

[11] Alternatively, one could also relax the integer constraint by letting $n_L^L \geq \epsilon$, where $1 > \epsilon > 0$. Following the discussion in the main body, in this case, the average cost also has flat segments to the left of the MES up to the point in which it reaches $n_L^L = \epsilon$. At this point the average cost jumps to the level of the MES of the new optimal (and lower) number of layers. Depending on the value of ϵ this will imply that the firm might decide to drop more than one layer. If ϵ is low enough, the average cost curve will be a step function with no smoothing declining segments. The lower is ϵ, the easier it is for the firm to produce less quantity with more layers, and in the limit, as $\epsilon \to 0$, firms converge to $L = \infty$. This case is counterfactual since we observe that in most cases firms expand by adding one layer at the time (see Section 3).

Assumption 1: *Firms face fixed production costs and their chosen price is an increasing function of their marginal cost.*

Proposition 1 *Given Assumption 1, a) Quantity-based productivity* ***increases*** *with a marginal increase in* λ *when the firm adds layers; b) Revenue-based productivity* ***decreases*** *with a marginal increase in* λ *when the firm adds layers.*

Proof. Without loss of generality we fix factor prices and focus on the problem of one firm. Denote the profits of a firm with demand draw λ producing with L layers by $\pi(\lambda, L) = P(\lambda, L) Q(\lambda, L) - \bar{C}(Q(\lambda, L); C_L(\cdot; 1), 1, 1) - F$, where we denote by $P(\lambda, L)$, and $Q(\lambda, L)$ the price and the quantity produced, respectively, given λ and L, and by F the fixed production costs. To ease notation we let $\bar{C}(Q(\lambda, L); C_L) \equiv \bar{C}(Q(\lambda, L); C_L(\cdot; 1), 1, 1)$. Denote by $\bar{\lambda}$ the level of demand at which the firm is indifferent between producing with L and $L+1$ layers; namely, $\pi\left(\bar{\lambda}, L\right) = \pi\left(\bar{\lambda}, L+1\right) \geq 0$.

We prove part a) of the proposition by contradiction. Consider first how quantity-based productivity changes when a firm at $\bar{\lambda}$ experiences demand $\bar{\lambda} + \varepsilon$, for $\varepsilon > 0$ infinitesimally small, and optimally decides to add a layer.[12] Toward a contradiction, suppose that quantity-based productivity is lower when the firm adds a layer, i.e.

$$\frac{Q\left(\bar{\lambda}, L+1\right)}{\bar{C}\left(Q\left(\bar{\lambda}, L+1\right); C_{L+1}\right)} \leq \frac{Q\left(\bar{\lambda}, L\right)}{\bar{C}\left(Q\left(\bar{\lambda}, L\right); C_L\right)}.$$

In the remainder of the proof we show that there exists an alternative feasible choice of quantity, $Q'\left(\bar{\lambda}, L+1\right)$, that attains higher profits than $Q\left(\bar{\lambda}, L+1\right)$, therefore contradicting the optimality of $Q\left(\bar{\lambda}, L+1\right)$. First, note that—as shown in Proposition 2 of CRH—since the minimum average cost for a given number of layers decreases with the number of layers, i.e.

$$Q_L^* \equiv \min_Q \frac{\bar{C}(Q; C_L)}{Q} \geq Q_{L+1}^* \equiv \min_Q \frac{\bar{C}(Q; C_{L+1})}{Q},$$

and the level of output that achieves this minimum increases with the number of layers, there exists a quantity $Q'\left(\bar{\lambda}, L+1\right) > Q\left(\bar{\lambda}, L\right)$ such that

$$\frac{Q\left(\bar{\lambda}, L+1\right)}{\bar{C}\left(Q\left(\bar{\lambda}, L+1\right); C_{L+1}\right)} \leq \frac{Q\left(\bar{\lambda}, L\right)}{\bar{C}\left(Q\left(\bar{\lambda}, L\right); C_L\right)} \leq \frac{Q'\left(\bar{\lambda}, L+1\right)}{\bar{C}\left(Q'\left(\bar{\lambda}, L+1\right); C_{L+1}\right)}. \tag{6}$$

Note that $Q'\left(\bar{\lambda}, L+1\right) > Q\left(\bar{\lambda}, L+1\right)$ always since $Q\left(\bar{\lambda}, L+1\right)$ is in the decreasing segment of the average cost curve, i.e. $Q\left(\bar{\lambda}, L+1\right) \leq Q_{L+1}^*$. To see this, note that if the firm had chosen a quantity level associated with the same average cost but on the increasing segment of the average cost curve, i.e.

[12] To ease notation we drop from the proof, from now on, ε.

$Q''\left(\bar{\lambda}, L+1\right) \geq Q_{L+1}^{*}$ such that

$$\frac{Q''\left(\bar{\lambda}, L+1\right)}{\bar{C}(Q''\left(\bar{\lambda}, L+1\right); C_{L+1})} = \frac{Q\left(\bar{\lambda}, L+1\right)}{\bar{C}\left(Q\left(\bar{\lambda}, L+1\right); C_{L+1}\right)},$$

the firm would have set lower prices and obtained lower profits. Therefore, $Q'\left(\bar{\lambda}, L+1\right) > Q\left(\bar{\lambda}, L+1\right)$.

Since the marginal cost is increasing in quantity—as shown in Proposition 1 of CRH—if prices are increasing in the marginal cost then $P(Q'\left(\bar{\lambda}, L+1\right)) \geq P(Q\left(\bar{\lambda}, L+1\right))$. Combined with inequality (6), the latter implies that

$$\frac{P(Q'\left(\bar{\lambda}, L+1\right))Q'\left(\bar{\lambda}, L+1\right)}{\bar{C}\left(Q'\left(\bar{\lambda}, L+1\right); C_{L+1}\right)} \geq \frac{P(Q\left(\bar{\lambda}, L+1\right))Q\left(\bar{\lambda}, L+1\right)}{\bar{C}\left(Q\left(\bar{\lambda}, L+1\right); C_{L+1}\right)}.$$

Since the cost function—as shown in Proposition 1 of CRH—is strictly increasing in quantity, *a fortiori*

$$P(Q'\left(\bar{\lambda}, L+1\right))Q'\left(\bar{\lambda}, L+1\right) - \bar{C}\left(Q'\left(\bar{\lambda}, L+1\right); C_{L+1}\right) \geq$$

$$\geq P(Q\left(\bar{\lambda}, L+1\right))Q\left(\bar{\lambda}, L+1\right) - \bar{C}\left(Q\left(\bar{\lambda}, L+1\right); C_{L+1}\right),$$

i.e. the profits associated with $Q'\left(\bar{\lambda}, L+1\right)$ are higher than those associated with $Q\left(\bar{\lambda}, L+1\right)$. This is a contradiction. Hence, quantity-based productivity is strictly higher after adding layers at $\bar{\lambda}$. So we have proven part a), namely, that quantity-based productivity **increases** with a marginal increase in λ when the firm adds layers.

We prove part b) of the proposition directly. Consider how revenue-based productivity changes when the firm with demand level $\bar{\lambda}$ adds a layer. Since $\pi\left(\bar{\lambda}, L\right) = \pi\left(\bar{\lambda}, L+1\right)$,

$$P\left(\bar{\lambda}, L+1\right) Q\left(\bar{\lambda}, L+1\right) - P\left(\bar{\lambda}, L\right) Q\left(\bar{\lambda}, L\right) = \bar{C}\left(Q\left(\bar{\lambda}, L+1\right); C_{L+1}\right) - \bar{C}\left(Q\left(\bar{\lambda}, L\right); C_{L}\right).$$

Since $\pi\left(\bar{\lambda}, L+1\right) \geq 0$ and $F > 0$, $P\left(\bar{\lambda}, L+1\right) Q\left(\bar{\lambda}, L+1\right) > \bar{C}\left(Q\left(\bar{\lambda}, L+1\right); C_{L+1}\right)$ which implies that

$$\frac{P\left(\bar{\lambda}, L+1\right) Q\left(\bar{\lambda}, L+1\right) - P\left(\bar{\lambda}, L\right) Q\left(\bar{\lambda}, L\right)}{P\left(\bar{\lambda}, L+1\right) Q\left(\bar{\lambda}, L+1\right)} < \frac{\bar{C}\left(Q\left(\bar{\lambda}, L+1\right); C_{L+1}\right) - \bar{C}\left(Q\left(\bar{\lambda}, L\right); C_{L}\right)}{\bar{C}\left(Q\left(\bar{\lambda}, L+1\right); C_{L+1}\right)},$$

or

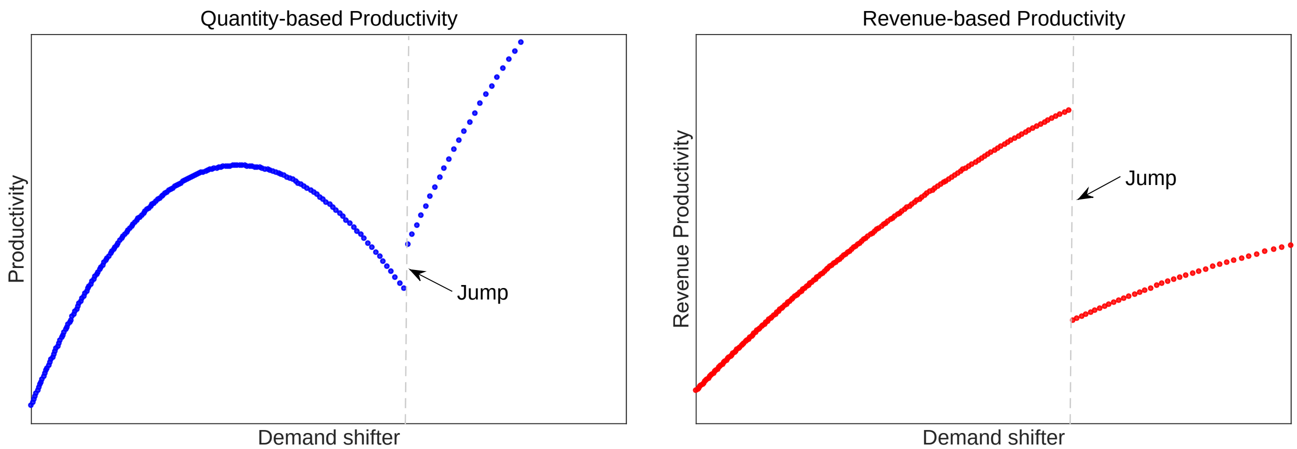
$$\frac{P\left(\bar{\lambda}, L\right) Q\left(\bar{\lambda}, L\right)}{\bar{C}\left(Q\left(\bar{\lambda}, L\right); C_{L}\right)} > \frac{P\left(\bar{\lambda}, L+1\right) Q\left(\bar{\lambda}, L+1\right)}{\bar{C}\left(Q\left(\bar{\lambda}, L+1\right); C_{L+1}\right)}.$$

Hence, we have proven part b), namely, that revenue-based productivity decreases with a marginal increase in λ when the firm adds layers. ■

This effect in both types of productivity is illustrated in Figure 2 where we consider the effect of a shock in λ that leads to a reorganization that adds one layer of management.

In sum, firms that add layers as a result of a marginal revenue shock increase their quantity discontinu-

Figure 2: Quantity and Revenue Productivity Changes as a Firm Adds Layers



ously. The new organization is more productive at the new scale, resulting in an increase in quantity-based productivity, but the quantity expansion decreases price and revenue-based productivity. When firms face negative shocks that make them drop layers we expect the opposite effects.

2.1.1 Some Portraits of Actual Reorganizations

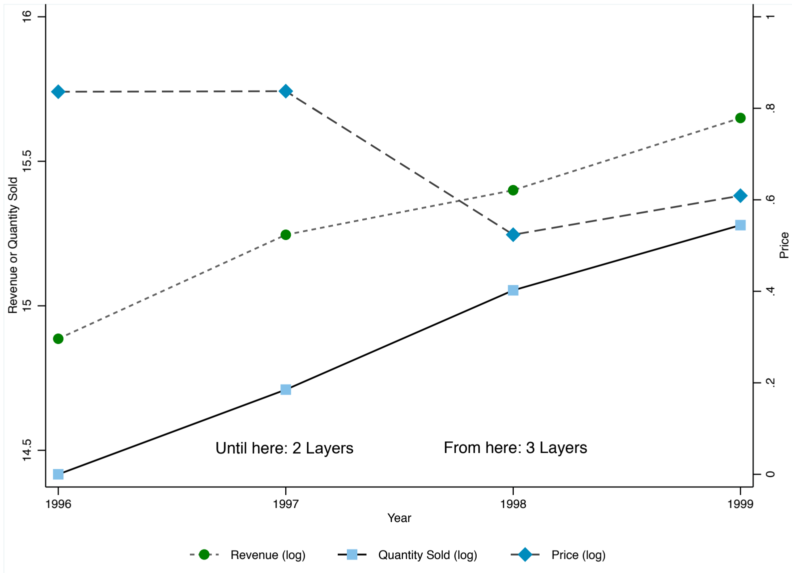
The mechanism described above is naturally an abstraction of reality. To illustrate the way in which firms actually reorganize in the data, we present a series of examples of firms that go through this process of reorganization. We choose a variety of examples that includes firms in many industries, some that grow and some that decline. For each example, we briefly describe the firm and the process of reorganization that it went through. In addition we show how quantity-based productivity, revenue-based productivity and value added per worker changed. The precise methodology and data used to measure quantity-based productivity and revenue-based productivity is presented in detail in Section 4.

Example: A Firm that Adds Layers

We start with the example of a single-product firm producing aluminium cookware (anonymous given confidentiality requirements). It increased its workforce over time and, in particular, by 27 percent between 1996 and 1998. In the same period exports increased by 170%, and went from representing 10% of the firms sales in 1996 to 16% in 1998. Between 1997 and 1998 the firm reorganized and added a layer of management.

Our firm had a layer of workers and a layer of managers until 1997 and it added a new layer of management in 1998 (so it went from 1 layer to 2 layers of management). As the theory suggests, its quantity-based productivity grew by 16.9 percent when we compare the two years prior to the reorganization (1996 and 1997) to the two years after it (1998 and 1999). In contrast, value added per worker fell by 15.8 percent and revenue-based productivity fell by 10 percent. Of course, we discuss the details of the estimation of both

Figure 3: An Example of a Firm that Adds Layers: Output, Price, and Revenue



types of productivity extensively below. In Section 5 we show that this pattern of changes in productivity is typical in our data when a firm increases the number of layers.

To explore this case further, Figure 3 shows the corresponding levels of output, prices and revenue for the same firm and time period. The graph shows how, in fact, the increase in quantity-based productivity is accompanied by an increase in quantity, a fairly large decrease in price, and a small increase in revenue. These changes align exactly with our story in which the increase in quantity-based productivity generated by the reorganization (that adds a layer of management) leads to an increase in quantity, a lower marginal cost that leads to a decline in price, and a correspondingly muted increase in revenue and decline in revenue-based productivity. Note that quantity in this firm grows not only at the time of the reorganization but before and after it as well. This is consistent with a firm that is progressively moving toward the quantity threshold at which it decides to reorganize. In these other years, demand and productivity shocks do not trigger a reorganization and so we do not see the corresponding decline in price.

Example: A Shock to Textile and Apparel Firms

One issue with the previous example is that we do not know what caused the growth of this firm. Fortunately, our sample covers the period in which China entered the WTO. So we now present two more examples of firms producing in the "Textile and Apparel" industry. The reorganization of these firms was arguably triggered by an exogenous event, namely, the reductions in quotas that resulted from China's entry into the WTO.[13]

[13] As a consequence of China joining the WTO a number of quotas that were imposed at the EU-level on Chinese imports—as well as on imports from other non-WTO countries—were removed. Later on, in Section 5.4, we describe in greater detail how we identify the shock and the implications that this shock had for the entire industry.

Table 1: Textile and Apparel Firm Reorganization, Nace 1772 Example

Firm with 3 Layers (2004)				
Occupation	Layer 0	Layer 1	Layer 2	Layer 3
Managers			1	2
Technicians and Assoc. Professionals		1		
Clerks	2			
Crafts Workers	15		4	
Plant and Machine Operators	11			
Elementary Occupations	1			
Firm with 2 Layers (2005)				
Managers				
Technicians and Assoc. Professionals		1	1	
Clerks		1		
Crafts Workers	4			
Plant and Machine Operators	1		1	
Elementary Occupations	1			

Notes: Occupations correspond to ISCO-88 1-digit major groups.

The first firm we analyze is one that was hit hard by the (quota) shock and that we already referred to in the introduction. The firm produces "Knitted and crocheted pullovers, cardigans, and similar articles" (Nace 1772). Between 2002 and 2005, as a result of the quota reduction, it downsizes rapidly. Table 1 illustrates the hierarchy of the firm before and after the reorganization resulting from the trade shock.[14] Labor force goes down from 37 to 10 employees. The quantity sold by the firm declines by 50 percent, value added by 70 percent, and prices increase by 35 percent. Imported inputs double. We see that the firm reorganizes and decreases the number of management layers from 3 to 2. Accordingly, and as expected, the firm exhibits a reduction in quantity-based productivity of 51 percent, an increase in revenue based productivity of 10.3 percent, and an increase in value-added per worker of 9.3 percent.

The reorganization of the firm takes a natural form. It fires the 3 managers it used to have (two in "production and operations" and one in "sales and marketing").[15] In lower layers, the firm fires its "fibre preparers" and "textile, leather pattern-makers and cutters" and now focuses on "sewers and embroiderers" (reduces the total number but hires a new one). Similarly, it fires a variety of machine operators to focus exclusively on "sewing-machine operators". It also fires the one designer it used to employ. The result is the elimination of the top layer, and reductions in employment in the bottom layers. Essentially, the firm focuses on its top tasks and substitutes some of the others by producing less and importing more

[14] As we describe later, throughout the paper we use the variable qualif (see Table A.1 in Appendix A) to map occupations to layers. However, for illustration purposes, while describing the reorganization of the firm we use the occupational variable profissão (which is built following ISCO-88). This variable allows us to talk about more concrete and detailed occupations like "Sewers and embroiderers".

[15] Note that within each of the broad occupational categories that we present in the table there are several subcategories of occupations that can map to different layers. In Appendix A we present in greater detail how we map occupations to layers based on the tasks performed and skill requirements (qualif). For example, in 2004 the firm has two clerks, a statistical and finance clerk and a stock clerk. The statistical and finance clerk has a qualif of 60 which corresponds to semi-skilled professionals (with higher numbers representing lower skilled employees). Based on this qualif we assign it to layer 0. The stock clerk has a qualif of 71 which corresponds to non-skilled professionals. Based on this qualif we assign it to layer 0 as well. The stock clerk is "fired" in 2005. The remaining statistical and finance clerk changes qualif from 60 to 51 which corresponds to skilled professional. Based on this qualif we assign it to layer 1. That is, this clerk got a promotion to a more demanding job.

Table 2: Textile and Apparel Firm Reorganization, Nace 1720 Example

Firm with 3 Layers (1999)				
Occupation	Layer 0	Layer 1	Layer 2	Layer 3
Professionals				3
Technicians and Assoc. Professionals	1	5	2	
Clerks	14	10	2	
Crafts Workers	17			
Plant and Machine Operators	71	2	1	
Elementary Occupations	17			
Firm with 2 Layers (2000)				
Professionals			2	
Technicians and Assoc. Professionals	1	5	2	
Clerks	16	8	1	
Crafts Workers	15			
Plant and Machine Operators	49	3	1	
Elementary Occupations	17			

Notes: Occupations correspond to ISCO-88 1-digit major groups.

intermediate goods. Even though the firm is shrinking tremendously, the workforce that remains now earns more, as our model predicts, with increases in median wages of 73 percent in layer 2, 33 percent in layer 1 and 3 percent in layer 0.

Our second example of a firm affected by the quota is a larger firm producing “Woven fabrics” (Nace 1720). This firm also goes through a substantial downsizing from 1999 to 2000. Quantity sold decreases by 46 percent, value added by 30 percent, but prices rise by 13.8 percent. In the previous example we saw that the firm shrank by focusing on its core activities. In contrast, this firm reduces its product scope. It specializes in cotton fabrics (its core product) and drops the production of synthetic fabrics. This is achieved with a reduction in the number of layers of management from 3 to 2, and a 46 percent smaller labor force. Correspondingly, the firm’s quantity-based productivity decreases by 11 percent but its revenue based productivity increases by 1.7 percent and value added per worker increases by 30 percent. Table 2 presents the organization of the firm before and after the reorganization.

The firm reduces the number of workers in the lowest layer by firing the workers that are not involved in the production process of the core product. The firm fires its “Fibre-preparing-, spinning- and winding-machine operators”, “Weaving- and knitting-machine operators”, “Bleaching-, dyeing- and cleaning-machine operators”, and “Steam-engine and boiler operators”. In addition, the firm reduces the number of designers (“Decorators and commercial designers”) from three, to one, to none within three years. Regarding the top layers of the firm, we see clear changes in its leading structure. In 1999 the top layer of the hierarchy includes 3 top management business professionals, specialized in accounting. In 2000 the firm drops the top layer. Layer 2, the new top layer, now focusses on dealing with less specialized tasks, including two middle management business professionals, and two administrative secretaries and related associate professionals—to "implement and support the communication, documentation and internal managerial coordination activities of an organizational unit to assist the head of unit" (ISCO 3411). As a result of the restructuring, the median wage in layer 0 goes up, by 7.5 percent, while in layers 1 and 2 they do not change much (reductions of 1.4 percent in median wages but an increase of 1 percent in the mean wages of layer 0).

Table 3: Footware Firm Reorganization, Nace 19301352 Example

Occupation	Layer 0	Layer 1	Layer 2	Layer 3
Firm with 3 Layers (1998)				
Managers				1
Technicians and Assoc. Professionals		1		
Clerks		1		1
Crafts Workers	56	1	1	
Elementary Occupations	9			
Firm with 2 Layers (1999)				
Managers				
Technicians and Assoc. Professionals		1		
Clerks		1		
Crafts Workers	47		2	
Elementary Occupations	7			

Notes: Occupations correspond to ISCO-88 1-digit major groups.

Example: Downsizing and Growing

These cases exemplified well the way in which the abstract mechanism highlighted by our theory works in practice. However, one concern is that the way the restructuring took place could be particular to the textile and apparel industry and not present in other industries. Therefore, we finish this section by briefly presenting two other examples: one of a negative shock to a firm in the footwear industry and one of a positive shock to a firm in the cork industry (where Portugal is a main producer).[16] In these cases we have not identified the exact source of the shock, but we observe similar, theory-consistent, behavior of firms as they expand or contract.

Consider a firm producing "Women's town footwear with leather uppers" (Nace 19301352) that goes through a downsizing process from 1998 to 1999. The firm experienced a reduction in value added of 10 percent, reduced its labor force from 71 to 58 workers, and switched from 3 to 2 layers of management. Accordingly, the firm's quantity-based productivity decreases by 20 percent, quantity sold decreases by 24 percent, and prices rise by 39 percent. Our theory predicts that when a firm reduced the number of layers we should observe an increase in revenue-based productivity conditional on past prices and other shocks (see Proposition 1). In all the previous cases, this conditioning did not seem to matter much. Here it does, since we observe revenue-based productivity decline by 12 percent even though value added per worker grows by 9 percent. Table 3 presents the organizational structure of the firm in 1998—the last year the firm has three layers of management—and in 1999—when the firm has 2 layers of management. The firm reorganizes by simplifying its management structure. The new organization has neither a manager nor a statistical and finance clerk. The firm also reduces the number of shoe makers (identified in the table as crafts workers). As a result of the restructuring, the median wage rises in all the pre-existing layers (by 3 percent in layer 2, 23 percent in layer 1, and 8 percent in layer 0).

Our final example studies a small firm producing "Manufacture of articles of cork, straw and plaiting materials" (Nace 2052) which goes through a growth spell between 2004 and 2005, experiencing a 3 percent

[16] Footwear and cork are two traditional Portuguese industries. For instance, footwear represents about 6 percent of Portuguese exports in the 1993-2009 period, while Portugal is the biggest producer of cork in the world.

Table 4: Cork Firm Reorganization, Nace 2052 Example

Occupation	Layer 0	Layer 1	Layer 2	Layer 3
Firm with 1 Layer (2004)				
Managers				
Clerks		1		
Crafts Workers	8	1		
Firm with 2 Layers (2005)				
Managers			2	
Clerks		1		
Crafts Workers	9			

Notes: Occupations correspond to ISCO-88 1-digit major groups.

increase in value added. The firm started with one layer of management and added another layer. Its labor force goes from 9 to 12 workers. As expected, the firm's quantity-based productivity increases by 13 percent, quantity sold increases by 28 percent, and prices decreases by 21 percent. Revenue-based productivity declines, but only by -0.2%, while value added per worker decreases by 29 percent, indicating again that the proper conditioning on past prices and shocks is relevant. Table 4 portraits the organizational structure of the firm before and after the reorganization. The structure of the firm remains simple, with the only addition of a layer of management that includes two production and operations department managers. The small reinforcement of layer 0, where the number of craft workers—all of them "wood treaters"—rises from 8 to 9, hides a more substantial churning, with two wood treater leaving the firm and three new ones entering. As a result of the restructuring, the median wage decreases in all the pre-existing layers (by 1.4 percent in layer 1, and 7 percent in layer 0).

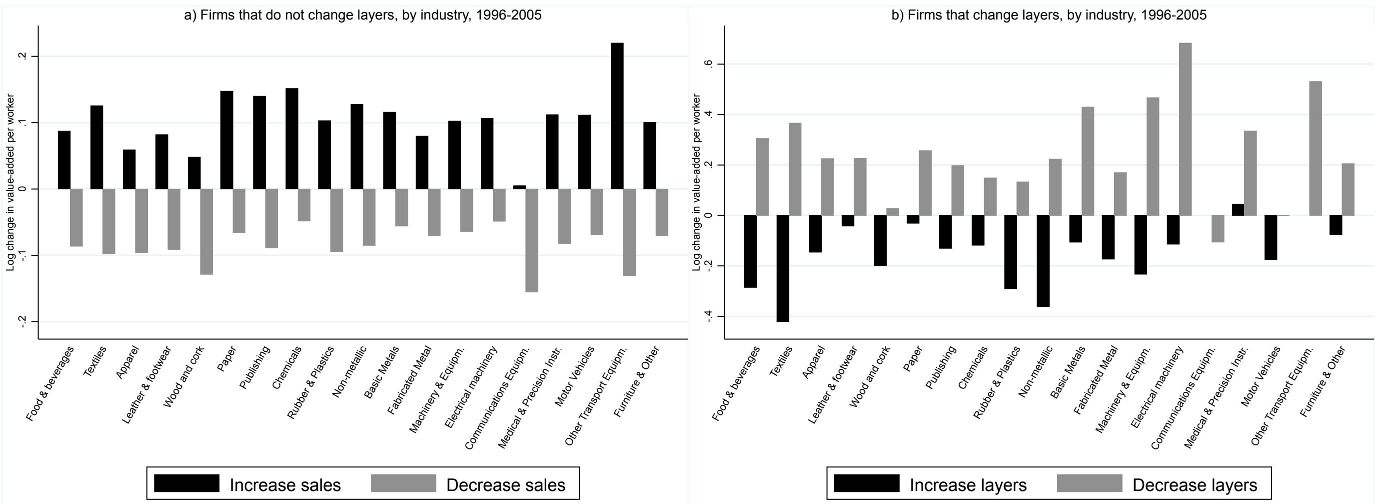
2.1.2 The Effect of Organization Across Industries: Some Simple Statistics

The arguments and examples presented so far indicate that when a firm receives a positive (negative) shock that makes it reorganize by adding (dropping) layers, its revenue-based productivity decreases (increases). Note, however, that this is the expected response only for firms that reorganize by changing the number of management layers. Firms that experience similar shocks but do not change layers expand much less, which implies that the price response is more muted, and so revenue-based productivity increases due to the direct effect of the reduction in costs. We now show evidence of these patterns at the sectoral level.

Figure 4 Panel a shows the change in value-added per worker between 1996 and 2005 by industry when we condition on firms that do not reorganize. Clearly, for firms that grow in terms of sales, value-added per worker increases as well. In contrast, firms that experience a decrease in total sales see their value-added per worker decline. The figure shows that all 19 industries exhibit this relationship. This is not surprising, after all revenue productivity and sales are positively related in many theories of the firm.

Figure 4 Panel b presents again the change in value-added per worker but now for firms that increase or decrease the number of layers. As predicted by our theory, but perhaps more surprising in light of the previous literature, in this case we see that firms that increase layers tend to decrease value-added per worker, and vice-versa for firms that drop layers. This is the case for all industries except "Communications

Figure 4: Reorganization and Value added per Worker



Equipment", "Medical and Precision Instruments" and "Other Transportation Equipment" where some of the effects are not significant. The switch in sign depending on whether a firm reorganizes or not is perhaps remarkable, given that increases (decreases) in sales are highly correlated with increases (decreases) in layers.

The examples above are illustrative, we believe, of the different forms that reorganizations take in practice. Sometimes firms focus or expand the set of production tasks performed, sometimes they restrict or increase the set of products produced, and sometimes they simply add or take away managerial structure to do less or more of the same. In all these cases, however, we find that the behavior of these firms exhibits the patterns we expect, even though these patterns are quite complicated and multidimensional. Not only do the firms reshuffle their labor force as predicted, but the wages they pay, as well as the implications for both types of productivity, are consistent with our mechanism. Of course, there are some exceptions, so the rest of the paper is dedicated to present systematic evidence of the ubiquitousness of these patterns as firms reorganize.

3 Data Description and Processing

Our data set is built from three data sources: a matched employer-employee panel data set, a firm-level balance sheet data set, and a firm-product-level data set containing information on the production of manufactured goods. Our data covers the manufacturing sector of continental Portugal for the years 1995-2005.[17] As explained below in detail, the matched employer-employee data virtually covers the universe of firms, while both the balance sheet data set and the production data set only cover a sample of firms. We build two nested samples. The largest of them sources information from the matched employer-employee data set for the subset of firms for which we also have balance sheet data. It contains balance sheet information but

[17] Information for the year 2001 for the matched employer-employee dataset was not collected. Hence, our sample excludes the year 2001 (see Appendix A).

no production data. We use it to provide basic statistics on firm organization. The smaller sample covers a subset of firms for which we also have production data. This data is necessary to calculate quantity-based productivity at the firm-product-year-level and so we use this sample in most of our analysis. Appendix A and B include further descriptions of these datasets.

Employer-employee data come from *Quadros de Pessoal* (henceforth, QP), a data set made available by the Ministry of Employment of Portugal, drawing on a compulsory annual census of all firms in Portugal that employ at least one worker.[18] Currently, the data set collects data on about 350,000 firms and 3 million employees. Reported data cover the firm itself, each of its plants, and each of its workers. Each firm and each worker entering the database are assigned a unique, time-invariant identifying number which we use to follow firms and workers over time. Variables available in the data set include the firm's location, industry, total employment, and sales. The worker-level data cover information on all personnel working for the reporting firms in a reference week in October of each year. They include information on occupation, earnings, and hours worked (normal and overtime). The information on earnings includes the base wage (gross pay for normal hours of work), seniority-indexed components of pay, other regularly paid components, overtime work, and irregularly paid components. It does not include employers' contributions to social security.[19]

The second data set is *Central de Balanços* (henceforth, CB), a repository of yearly balance sheet data for non financial firms in Portugal. Prior to 2005 the sample was biased towards large firms. However, the value added and sales coverage rate was high. For instance, in 2003 firms in the CB data set accounted for 88.8 percent of the national accounts total of non-financial firms' sales. Information available in the data set includes a firm sales, material assets, costs of materials, and third-party supplies and services.

The third data set is the *Inquérito Anual à Produção Industrial* (henceforth, PC), a data set made available by Statistics Portugal (INE), containing information on sales and volume sold for each firm-product pair for a sample of firms with at least 20 employees covering at least 90 percent of the value of aggregate production. From PC we use information on the volume and value of a firm's production. The volume is recorded in units of measurement (number of items, kilograms, liters) that are product-specific while the value is recorded in current euros. From the raw data it is possible to construct different measures of the volume and value of a firm's production. For the sake of this project we use the volume and value corresponding to a firm's sales of its products. This means that we exclude products produced internally and to be used in other production processes within the firm as well as products produced for other firms, using

[18] Public administration and non-market services are excluded. *Quadros de Pessoal* has been used by, amongst others, Blanchard and Portugal (2001) to compare the U.S. and Portuguese labor markets in terms of unemployment duration and worker flows; by Cabral and Mata (2003) to study the evolution of the firm size distribution; by Mion and Opromolla (2014) to show that the export experience acquired by managers in previous firms leads their current firm towards higher export performance, and commands a sizeable wage premium for the manager.

[19] The Ministry of Employment implements several checks to ensure that a firm that has already reported to the database is not assigned a different identification number. Similarly, each worker also has a unique identifier, based on a worker's social security number. The administrative nature of the data and their public availability at the workplace—as required by the law—imply a high degree of coverage and reliability. It is well known that employer-reported wage information is subject to less measurement error than worker-reported data. The public availability requirement facilitates the work of the services of the Ministry of Employment that monitor the compliance of firms with the law.

inputs provided by these other firms. The advantage of using this definition is that it nicely corresponds to the cost of materials coming from the balance sheet data. For example, the value of products produced internally and to be used in other production processes within the firm is part of the cost of materials while products produced for other firms, using inputs provided by these other firms, is neither part of the cost of materials nor part of a firm's sales from the PC data. We aggregate products at the 2-digits-unit of measurement pairs and split multi-products firms into several single-product firms using products revenue shares as weights (see Appendix A).[20]

3.1 Occupational Structure

To recover the occupational structure at the firm level we exploit information from the matched employer-employee data set. Each worker, in each year, has to be assigned to a category following a (compulsory) classification of workers defined by the Portuguese law.[21] Classification is based on the tasks performed and skill requirements, and each category can be considered as a level in a hierarchy defined in terms of increasing responsibility and task complexity. Table A.1 in Appendix A contains more detail about the exact construction of these categories.

On the basis of the hierarchical classification and taking into consideration the actual wage distribution, we partition the available categories into management layers. We assign "Top executives (top management)" to occupation 3; "Intermediary executives (middle management)" and "Supervisors, team leaders" to occupation 2; "Higher-skilled professionals" and some "Skilled professionals" to occupation 1; and the remaining employees, including "Skilled professionals", "Semi-skilled professionals", "Non-skilled professionals", and "Apprenticeship" to occupation 0.

We then translate the number of different occupations present in a firm into layers of management. A firm reporting c occupational categories will be said to have $L = c - 1$ layers of management: hence, in our data we will have firms spanning from 0 to 3 layers of management (as in CMRH). In terms of layers within a firm we do not keep track of the specific occupational categories but simply rank them. Hence a firm with occupational categories 2 and 0 will have 1 layer of management, and its organization will consist of a layer 0 corresponding to some skilled and non-skilled professionals, and a layer 1 corresponding to intermediary executives and supervisors.[22]

[20] In our analysis, we also experimented with using the sample of single-product firms only. Results, available upon request, are qualitatively identical and quantitatively very similar.

[21] Following CMRH we use occupational categories to identify layers of management. In the case of French firms, CMRH use the PCS classification. In this study we use the Portuguese classification (Decreto Lei 121/78 of July 2^{nd} 1978) which is not the ISCO.

[22] One potential concern with this methodology to measure the number of layers is that many firms might have layers with occupations that are not adjacent in the rank. This does not seem to be a large problem. More than 75% of firms have adjacent layers.

3.2 Portuguese Production Hierarchies: Basic Facts

In this section we reproduce some of the main results in CMRH for France using our largest, but less complete, dataset for Portugal. We focus here on the main findings and, for brevity, we relegate all the tables and figures with the exact results to Appendix B.

Firms with different numbers of layers are different. If we group firms by their number of management layers, firms with more layers are larger in terms of value added, hours, and that they pay on average higher wages (see Table B-2). In fact, the distributions of value added, employment, and the hourly wage by layer for firms with more layers are shifted to the right and exhibit higher variance (see Figures B-1 to B-3). Thus, these results underscore our claim that the concept of layers we use is economically meaningful.

Our definition of layers of management is supposed to capture the hierarchical structure of the firm. So it is important to verify that the implied hierarchies are pyramidal in the sense that lower layers employ more hours and pay lower hourly wages. The implied hierarchical structure of firms is hierarchical in the majority of cases (Table B-3). The implied ranking holds for 76% of the cases when comparing any individual pair of layers. As for compensation, employees in lower layers command lower wages in the vast majority of cases (Table B-4). For example, the proportion of firms that exhibits a hierarchical ranking for any given bilateral comparison between layers is also greater than 75%. We conclude that, although with some exceptions, our definition of layers does a good job in capturing the hierarchical structure of firms.

Our primary goal is to study the endogenous productivity responses of firm that reorganize. So it is important to establish how often they do so.[23] In a given year about half the total number of firms keep the same number of layers, with the number increasing to 70% for firms with 4 layers (3 layers of management). Most of the firms that do not reorganize just exit, with the percentage of exiting firms declining with the number of layers. About 12% of firms in a layer reorganize by adding a layer, and about the same number downscale and drop one. Overall, as in France, there seem to be many reorganizations in the data. Every year around 20% of firms add and drop occupations, and therefore restructure their labor force (the number is lower for firms with 3 layers of management since, given that the maximum number of management layers is 3, they can only drop layers).

A reorganization is accompanied with many other firm-level changes. To see this, we divided firms depending on whether they add, do not change, or drop layers, and present measured changes in the total number of hours, number of hours normalized by the number of hours in the top layer, value added, and average wages. First, we find that firms that either expand or contract substantially do so by reorganizing. This is the case both in terms of hours and value added. Furthermore, changes in either hours or value added seem to be symmetric, but with opposite sign, for firms that add or drop layers. After detrending, firms that add (drop) layers tend to pay higher (lower) average wages. However, once we focus on average wages in preexisting layers wages decline (increase), as the theory predicts. So, in firms that add layers, average wages increase because the agents in the new layer earn more than the average but workers in preexisting

[23] Table B-5 presents a transition matrix across layers.

layers earn less as their knowledge is now less useful (as found for France in CMRH).[24]

The results above can be further refined by looking at layer-level outcomes for firms that expand without reorganizing and firms that expand as a result of a reorganization. The theory predicts that firms that expand but keep the same number of layers will increase employment and wages in all layers. In contrast, firms that expand and add layers, will increase employment in all layers but will decrease wages (and according to the theory, knowledge) in all preexisting layers. That is, adding a layer allows the firm to economize on the knowledge of all the preexisting layers. Hence, we expect the elasticity of normalized hours (hours at each layer relative to the top layer) and wages, respectively, to value added for firms that do not add layers to be positive. This prediction is confirmed for all elasticities except for one case where the estimate is not significant (see Tables B-7 and B-8). We conclude that firms that grow without reorganizing increase employment and wages in all layers.

Adding layers should lead to increases in employment but declines in wages in all preexisting layers. These implications are verified for all transitions in all layers except for two non-significant results for firms that start with zero layers of management (see Table B-9). Similar to the results in CMRH for France, our estimates for Portugal show that firms that add layers in fact concentrate workers' knowledge, as proxied by their wages, on the top layers. This is one of the consequences of a firm reorganization and supports empirically the underlying mechanism that, we hypothesize, leads to an increase (decrease) in quantity-based productivity as a result of a reorganization that adds (drops) layers.

4 Estimation

We now present our methodology, based on Forlani et al., (2015), to measure changes in revenue-based and quantity-based productivity induced by firm reorganization. We first discuss our production and timing assumptions, preferences and market structure. After that, we define the stochastic process for productivity and demand. Finally, we discuss our estimation strategy and derive our estimating equations to estimate the parameters of the production function and the effects of changes in layers on productivity.

4.1 Production

A firm's technology is given by the production function in (1), which we have discussed before. A full specification of the production process requires us to take a stand on the timing of firm's decisions relative to the realization of productivity and demand shocks. We assume that capital, K_{it} is chosen by the firm prior to the realization of shocks in t. We also assume that at some time between period $t-1$ and t the firm has some knowledge about the realizations of the productivity and demand shocks (which we will denote by ν_{ait} and $\nu_{\lambda it}$, respectively) materializing in t. It is at this point that the firm chooses the number of layers. Hence, we allow current period shocks to impact the choice of the number of layers L_{it}, but not of the capital stock K_{it}. Of course, past capital and past numbers of layers, K_{it-1} and L_{it-1}, as well as

[24] All these results are presented in Table B-6.

lagged productivity and demand shocks, can affect the number of layers too. All other inputs are chosen conditional on the realization of shocks, as well as the current period capital and number of layers.

Denote by O^*_{it} the constrained, by the number of management layers, labor input choice the firm makes in t.[25] Note that O^*_{it} is not directly observable, but we can use that $O^*_{it} = C\left(O^*_{it}; w_t\right)/AC\left(O^*_{it}; w_t\right)$, where $C\left(O^*_{it}; w_t\right)$, is the total expenditure on the labor input, i.e., the total wage bill of the firm (which is observable), and $AC\left(O^*_{it}; w_t\right)$ is the unit cost of the labor input which is not observable and depends on the number of layers. Hence, the production function (1) in logs becomes,

$$q_{it} = \tilde{a}_{it} + \alpha_O \ln C\left(O^*_{it}; w_t\right) + \alpha_M m_{it} + (\gamma - \alpha_M - \alpha_O)k_{it}, \tag{7}$$

where $\tilde{a}_{it} = \ln \tilde{A}_{it} \equiv \ln A_{it} - \alpha_O \ln AC\left(O^*_{it}; w_t\right)$. Hence, measured quantity-based productivity $\tilde{a}_{it}$ depends on the number of layers L_{it} through the term O^*_{it}.[26] Note that, *conditional on the total wage bill*, $C\left(O^*_{it}; w_t\right)$, the number of layers is not a traditional input in that it does not cost the firm anything. Hence, it is more natural to treat it as a characteristic of the firm that determines the ability to transform inputs (including the labor input through the total wage bill, as well as capital and materials) into output. In this sense, it parallels a firm's technological capabilities, so we treat them in a similar way.

4.2 Demand and Market Structure

We assume the presence of a representative consumer with generalized CES preferences (Spence, 1976). The inverse demand is then given by

$$P_{it} = \Lambda_{it}^{(\eta_{it}-1)/\eta_{it}} Q_{it}^{-1/\eta_{it}},$$

where Λ_{it} is a demand shifter, η_{it} the elasticity of demand, and P_{it} and Q_{it} are the price and quantity of variety i respectively. Multiplying both sides by quantity and taking logs we obtain the following expression for revenue,

$$r_{it} = \left(1 - \frac{1}{\eta_{it}}\right)(\lambda_{it} + q_{it}), \tag{8}$$

where lower case letters denote log values. Namely, $\lambda_{it} = \ln \Lambda_{it}$, $q_{it} = \ln Q_{it}$, and $r_{it} = \ln R_{it}$.

We consider a monopolistically competitive environment. Hence, given preferences, markups are given by

$$\mu_{it} = \frac{\eta_{it}}{\eta_{it} - 1}.$$

From the first-order-conditions of the cost minimization problem, we obtain that markups will equal the ratio of the output elasticity of the optimized input to the share of that input expenditure in revenue (Hall, 1986). Defining $s_{Mit} = \frac{W_{Mt} M_{it}}{R_{it}}$ as the revenue expenditure share on materials, where W_{Mt} is the price of

[25] The firm in t can choose the number of workers in each layer and the amount of knowledge in each layer.

[26] Note that $-\alpha_O \ln AC\left(O^*_{it}; w_t\right) = \beta L_{it}$ is what is implied by the CRH model if we substitute the constraint $n^L_L = 1$ in the organizational problem with $n^L_L \geq \epsilon$, for small enough $\epsilon > 0$ as we discussed in Section 2. Hence, in that case, $\tilde{a}_{it} = a_{it} + \beta L_{it}$.

materials (and equivalently s_{Oit} on the labor input), it follows that markups are given by

$$\mu_{it} = \tfrac{\alpha_M}{s_{Mit}} = \tfrac{\alpha_O}{s_{Oit}}. \tag{9}$$

Therefore, with estimates of the production function parameters, we can recover μ_{it} by simply combining them with data on revenue and expenditures.

4.3 Assumptions on the Stochastic Processes for Productivity and Demand

We denote by $\tilde{a}_{it}$ the log of quantity-based productivity, and assume that it follows a stochastic process. In particular, we assume that

$$\tilde{a}_{it} = \begin{cases} \alpha_i + \delta_t + \phi_a \tilde{a}_{it-1} + \nu_{ait} & \text{if } \Delta L_{it} = 0 \\ \alpha_i + \delta_t + \phi_a \tilde{a}_{it-1} + \phi_L \Delta L_{it} + \nu_{ait} & \text{if } \Delta L_{it} \neq 0 \end{cases}, \tag{10}$$

where $\Delta L_{it} = L_{it} - L_{it-1}$ is the change in the number of management layers between $t-1$ and t and where ν_{ait} is a mean zero productivity shock that is i.i.d. across firms and time. α_i and δ_t represent, respectively, firm-product and time fixed effects. We incorporate the effect of changes in the number of layers on measured quantity-based productivity, implied by equation (7), parsimoniously through the term ΔL_{it}.

Regarding the demand process, we assume the following stochastic process for demand shifters

$$\lambda_{it} = \delta_t^{\lambda} + \phi_\lambda \lambda_{it-1} + \nu_{\lambda it}, \tag{11}$$

where $\nu_{\lambda it}$ is an idiosyncratic mean zero demand shock that is i.i.d. across firms and time and that can potentially be correlated with the productivity shock ν_{ait}.

We further assume that ν_{ait} and $\nu_{\lambda it}$ are uncorrelated with past values of productivity and demand and, more generally, with all past variables. Precisely, we assume that

$$E\left[\nu_{ait}\tilde{a}_{is}\right] = E\left[\nu_{ait}\lambda_{is}\right] = E\left[\nu_{\lambda it}\tilde{a}_{is}\right] = E\left[\nu_{\lambda it}\lambda_{is}\right] = 0 \quad \forall s < t.$$

Given our timing assumption for L_{it}, it follows that

$$E\left[\nu_{ait}L_{it}\right] \neq 0; \quad E\left[\nu_{\lambda it}L_{it}\right] \neq 0, \tag{12}$$

and likewise that

$$E\left[\nu_{ait}\Delta L_{it}\right] \neq 0; \quad E\left[\nu_{\lambda it}\Delta L_{it}\right] \neq 0. \tag{13}$$

Regarding capital, $k_{it} = \ln K_{it}$, our timing assumptions imply that

$$E\left[\nu_{ait}k_{it}\right] = E\left[\nu_{\lambda it}k_{it}\right] = 0. \tag{14}$$

Note that the total cost of the labor input $C(O_{it}^{*}; w_t)$ conditional on the number of layers and materials, $m_{it} = \ln M_{it}$, are endogenous to both current productivity and demand shocks, namely

$$E\left[\nu_{ait} \ln C\left(O_{it}^{*}; w_t\right)\right] \neq 0; \text{ and } E\left[\nu_{\lambda it} \ln C\left(O_{it}^{*}; w_t\right)\right] \neq 0, \qquad (15)$$
$$E\left[\nu_{ait} m_{it}\right] \neq 0; \text{ and } E\left[\nu_{\lambda it} m_{it}\right] \neq 0.$$

Finally, given estimates of the production function we can compute revenue-based productivity $\bar{a}_{it}$ simply by adding the log price. That is,

$$\begin{aligned} \bar{a}_{it} &= p_{it} + \tilde{a}_{it}, \\ &= r_{it} - \alpha_O \ln C\left(O_{it}^{*}; w_t\right) - \alpha_M m_{it} - \left(\gamma - \alpha_M - \alpha_O\right) k_{it}. \end{aligned} \qquad (16)$$

4.4 Estimating Strategy

Our estimating strategy is to first estimate the parameters of the production function $(\alpha_O, \alpha_M, \gamma)$. With these estimates, we obtain quantity and revenue-based productivities and use the process in equation (10) to obtain the equations to estimate ϕ_a and ϕ_L. Finally, we incorporate firm-product fixed effects in the estimation.

4.4.1 Production Function Estimation

To derive our estimating equation, we start by substituting the production function (7) into the revenue equation (8).[27] We then use the measure of markups (9) and substitute $\tilde{a}_{it-1}$ from (10) and λ_{it-1} from (11) as a function of observables. Here, we drop the firm-product fixed effects in order to minimize problems coming from measurement errors, as suggested in the literature (Griliches and Mairesse, 1998). We incorporate firm-product fixed effects again in the final step of the estimation. The resulting equation is

$$LHS_{it} = \delta_t^q + b_1 k_{it} + b_2 LHS_{it-1} + b_3 k_{it-1} + b_4 \frac{r_{it-1}}{s_{Mit-1}} + b_5 q_{it-1} + b_6 \Delta L_{it} + u_{it}, \qquad (17)$$

where

$$LHS_{it} = \frac{r_{it} - s_{Oit}\left(\ln C\left(O_{it}^{*}; w_t\right) - k_{it}\right) - s_{Mit}\left(m_{it} - k_{it}\right)}{s_{Mit}},$$

$\delta_t^q = \frac{1}{\alpha_M}(\delta_t + \delta_t^{\lambda})$, $b_1 = \frac{\gamma}{\alpha_M}$, $b_2 = \phi_a$, $b_3 = -\gamma\frac{\phi_a}{\alpha_M}$, $b_4 = \phi_\lambda - \phi_a$, $b_5 = \frac{1}{\alpha_M}(\phi_a - \phi_\lambda)$, $b_6 = \frac{\phi_L}{\alpha_M}$, and $u_{it} = \frac{1}{\alpha_M}(\nu_{ait} + \nu_{\lambda it})$.

In order to estimate the parameters of the production function using (17) we need to deal with two issues. First, that the error term u_{it} might be correlated with at least one of the regressors, and second, identification of the parameters $(\alpha_O, \alpha_M, \gamma)$ requires point estimates $\hat{b}_5$ to be significantly different than

[27] Please refer to Appendix C for a detailed derivation of all the expressions in this section.

zero. Then,

$$\hat{\alpha}_O = -\frac{s_{Oit}}{s_{Mit}} * \hat{b}_4/\hat{b}_5, \quad \hat{\alpha}_M = -\hat{b}_4/\hat{b}_5, \quad \hat{\gamma} = -\hat{b}_1 * \hat{b}_4/\hat{b}_5.$$

To deal with the first issue we propose an instrument consistent with the model and timing introduced above. Note that given (12), and (14), the error term u_{it} is uncorrelated with all regressors except ΔL_{it}. Hence, we can simply instrument ΔL_{it} with ΔL_{it-1} and L_{it-2}.

Regarding the second issue, note that $b_5 > 0$ implies that the autoregressive parameters of demand and productivity are significantly different from each other (recall that $b_5 = \frac{1}{\alpha_M}(\phi_a - \phi_\lambda)$). As we argue below, this is a problem in practice. In the estimation we find that in many industries $\hat{b}_5$ is not significantly different from zero.

To deal with this practical issue, we can proceed as follows. Substitute $\tilde{a}_{it-1}$ into $\tilde{a}_{it}$ from (10) (after again dropping the firm-product fixed effects in order to minimize problems coming from measurement errors) into the production function (7). Then use the estimates of $\hat{b}_1$ and $\hat{b}_2$ to compute

$$Z_{it} = \frac{1}{\hat{b}_1}\frac{s_{Oit}}{s_{Mit}}\left(\ln C\left(O_{it}; w_t\right) - k_{it}\right) + \frac{1}{\hat{b}_1}\left(m_{it} - k_{it}\right) + k_{it} + \frac{\hat{b}_2}{\hat{b}_1} LHS_{it-1} - \hat{b}_2 k_{it-1} - \frac{1}{\hat{b}_1}\frac{\hat{b}_2}{s_{Mit-1}} r_{it-1},$$

and substitute to obtain the estimating equation,

$$q_{it} - \hat{b}_2 q_{it-1} = \delta_t + b_7 Z_{it} + b_8 \Delta L_{it} + \nu_{ait}. \tag{18}$$

Note that in light of (13) and (15), the variables Z_{it} and ΔL_{it} are endogenous so we require instruments. Based on (12) and (14) we can use k_{it}, ΔL_{it-1} and L_{it-2} as instruments. Using this second estimating equation we can obtain identification of the parameters $(\alpha_O, \alpha_M, \gamma)$ using

$$\hat{\alpha}_O = \frac{\hat{b}_7}{\hat{b}_1}\frac{s_{Oit}}{s_{Mit}}, \quad \hat{\alpha}_M = \frac{\hat{b}_7}{\hat{b}_1}, \quad \hat{\gamma} = \hat{b}_7.$$

Finally, after estimating the parameters of the production function, our estimate of the quantity-based productivity process is given by

$$\hat{\tilde{a}}_{it} = q_{it} - \hat{\alpha}_O\left(\ln C\left(O_{it}; w_t\right) - k_{it}\right) - \hat{\alpha}_M\left(m_{it} - k_{it}\right) - \hat{\gamma} k_{it},$$

and our estimate of revenue-based productivity by

$$\hat{\tilde{a}}_{it} = r_{it} - \hat{\alpha}_O\left(\ln C\left(O_{it}; w_t\right) - k_{it}\right) - \hat{\alpha}_M\left(m_{it} - k_{it}\right) - \hat{\gamma} k_{it}.$$

With the measures of quantity and revenue-based productivity in hand, we can estimate the effect of changes in layers on both types of productivity using equations (10) and (16), where we incorporate product or firm-product fixed effects, as well as time fixed effects.[28] In this step, the endogeneity of ΔL_{it} can be addressed as in the previous steps, or using a specific exogenous shock. We pursuit both strategies below.

5 Results

Following our estimation strategy, we first use (17) to estimate the parameters of the production function. Table D-1 in Appendix D presents the results. Note that $\hat{b}_5$ is significantly different from zero only in 2 out of 42 cases. Thus, as explained above, we are not able to identify α_M and γ directly. We then proceed to use the estimates of b_1 and b_2, together with specification (18), to estimate $(\alpha_O, \alpha_M, \gamma)$ and obtain our productivity processes. The estimates $\hat{b}_1$ and $\hat{b}_2$ are significantly different from zero in all cases (see Table D-1 where we present Bootstrapped standard errors).

5.1 Estimating Equations

Armed with our structurally estimated productivity processes, we use (10) to derive our estimating equation for quantity-based productivity:

$$\tilde{a}_{it} = \alpha_i + \delta_t + \phi_a \tilde{a}_{it-1} + \phi_L \Delta L_{it} + \nu_{ait}. \tag{19}$$

An observation, it, corresponds to a firm-product-sequence i at time t. A firm-product is a 2 digit Prodcom code-firm combination. Furthermore, in the regressions below we use it sequences with either one change or no change in layers to better pinpoint re-organization events. In case of a change in layers the change might be either increasing or decreasing the number of layers. So we have 4 cases: increasing sequences; decreasing sequences; constant sequences; all the above sequences.

The underlying idea is to compare the productivity of firms that are, for example, increasing the number of layers both among them as well as with firms that are not changing the number of layers. In the former case, we obtain identification of the impact on productivity via comparing firms increasing the number of layers before and after the change. In the latter case we also get identification from comparing the productivity of firms changing layers with those that do not. To better isolate reorganization events and ease comparability of an otherwise complex structure we break firms into sequences that correspond to at most one change in the hierarchical structure.[29]

[28] This last step is similar to standard approaches aimed to find determinants of productivity (see De Loecker et al., 2016 and Foster et al., 2008)

[29] More specifically, we define a sequence of type $L - L'$ as the series of years in which a firm has the same consecutively observed number of management layers L plus the adjacent series of years in which a firm has the same consecutively observed number of management layers L'. For example, a firm that we observed all years between 1996 and 2000 and that has one layer in 1996, 1997, and 2000 and two layers in 1998 and 1999 would have two sequences: A 1-2 sequence (1996 to 1999) as well as a 2-1 sequence (1998 to 2000). Firms that never change layers in our sample form a constant-layer sequence. We then separately analyze sequences characterized by an increasing, decreasing or constant number of layers as well as all sequences together. As a result, each firm-product can "produce" multiple sequences: for example, a firm-product with 1 layer for three years, then 2 layers for an additional three years, and then back to 1 layer for three more years gives rise to two sequences, an increasing one

In order to derive the estimating equation for revenue-based productivity we use the fact that $\tilde{a}_{it} = \bar{a}_{it} - p_{it}$, and together with the process for productivity (10) we obtain that

$$\bar{a}_{it} = \alpha_i + \delta_t + \phi_a \bar{a}_{it-1} + \phi_L \Delta L_{it} + p_{it} - \phi_a p_{it-1} + \nu_{ait}. \tag{20}$$

Prices are functions of marginal costs which in turn are functions of quantities and hence productivities. As a result, we use the first order conditions of the cost minimization problem to substitute for prices into (20) to derive the following estimating equation

$$\bar{a}_{it} = \bar{\alpha}_i + \bar{\delta}_t + \bar{\phi}_a \bar{a}_{it-1} + \bar{\phi}_L \Delta L_{it} + \bar{\phi}_R X_{it} + \nu_{\bar{a}it}, \tag{21}$$

where $X_{it} = [\lambda_{it-1}, p_{it-1}, \ln(\mu_{it}), k_{it}]$. Appendix C.2 includes a step by step derivation of this equation.

5.2 Reorganization and Quantity-based Productivity

5.2.1 OLS

We start by presenting the results using simply OLS, namely, ignoring the potential endogeneity of ΔL_{it}. The specification we run is (19),

$$\tilde{a}_{it} = \alpha_s + \delta_t + \phi_a \tilde{a}_{it-1} + \phi_L \Delta L_{it} + \nu_{ait}, \tag{22}$$

where we substitute α_i for an industry/product fixed effect, α_s, to reduce the number of fixed effects.

Table 5: Quantity-based TFP. OLS estimator with product fixed effects.

VARIABLES	(1) Increasing	(2) Decreasing	(3) Constant	(4) All
QTFP t-1	0.892[a]	0.875[a]	0.905[a]	0.895[a]
	(0.014)	(0.015)	(0.013)	(0.008)
Change in layers	0.025[b]	0.032[a]		0.025[a]
	(0.011)	(0.012)		(0.007)
Constant	-0.161[b]	0.112[a]	0.309[b]	0.082[b]
	(0.063)	(0.035)	(0.130)	(0.033)
Observations	4,141	2,829	3,031	10,001
Adjusted R^2	0.779	0.752	0.801	0.781

Firm-level clustered standard errors in parentheses. Year and Industry dummies are included in the estimations. [a] p<0.01, [b] p<0.05, [c] p<0.1

Table 5 provides OLS estimation results. In all the results in this section we present standard errors clustered at the firm level. All of the point estimates of ϕ_L are positive and significant and point to an

(111222), and a decreasing one (222111).

impact of reorganization on quantity-based productivity of about 3%. Adding (dropping) a layer increases (decreases) quantity-based TFP by around 3%. We find that downward transitions seem to be characterized by somewhat larger effects than upward transitions.

5.2.2 IV

There are two issues with specification (19). The first issue is that ΔL_{it} is endogenous. The second issue is that due to the simultaneous presence of fixed effects and the lagged dependent variable, the usual strategy of first differencing the estimating equation to remove panel effects may create problems in the presence of predetermined variables, such as the lags of the dependent variable.

We deal with the first issue by instrumenting ΔL_{it} using demand, λ_{it-1}, and markups, μ_{it-1}, at time $t-1$, number of layers, revenue and quantity in $t-1$, productivity at time $t-2$, capital at time t, as well as all of these variables lagged to the first available year. All of these variables meet the requirements of good instruments under the timing assumptions of our model. In order to deal with the second issue, and incorporate a full set of firm-product-sequence fixed effects exactly as in (19), we use the Dynamic Panel Data system GMM estimator developed in Arellano and Bover (1995).

Table 6 reports the estimations of the structural quantity-based TFP equation. The results show a positive relationship between changes in layers and quantity-based productivity even when controlling for changes in quantity and allowing both variables to be endogenous. Coefficients are positive and significant. Point estimates are larger than before where the effect of a firm adding a layer is 3% and dropping layers is 5%. We find a larger effect of around 6% when we pull all the observations in column 4, though.

Table 6: Quantity-based TFP. Dynamic panel data estimator with firm-product-sequence fixed effects.

VARIABLES	(1) Increasing	(2) Decreasing	(3) Constant	(4) All
QTFP t-1	0.912^{a}	0.880^{a}	0.926^{a}	0.910^{a}
	(0.012)	(0.018)	(0.014)	(0.008)
Change in layers	0.037^{b}	0.052^{b}		0.062^{a}
	(0.017)	(0.023)		(0.016)
Constant	-0.014	0.127	0.211^{a}	0.116^{a}
	(0.016)	(0.123)	(0.042)	(0.031)
Observations	4,141	2,829	3,031	10,001
Number of fixed effects	1,663	1,274	1,290	4,227
AR(2) Test Stat	0.468	0.117	2.443	1.980
P-value AR(2)	0.640	0.907	0.015	0.048

Firm-level clustered standard errors in parentheses. Year and Industry dummies are included in the estimations. ^{a} p<0.01, ^{b} p<0.05, ^{c} p<0.1

5.3 Reorganization and Revenue-based Productivity

The purpose of this section is to study the relationship between organization and revenue-based productivity. As we did before, we start by showing the OLS results first and then the IV.

5.3.1 OLS

The specification we run is, following (21),

$$\bar{a}_{it} = \bar{\alpha}_s + \bar{\delta}_t + \bar{\phi}_a \bar{a}_{it-1} + \bar{\phi}_L \Delta L_{it} + \bar{\phi}_R X_{it} + \nu_{\bar{a}it}, \tag{23}$$

where $X_{it} = [\lambda_{it-1}, p_{it-1}, \ln(\mu_{it}), k_{it}]$ and, as we did before, we use an industry/product fixed effect, $\bar{\alpha}_s$, to reduce the number of fixed effects.

Table 7 presents the results. All of the point estimates of $\bar{\phi}_L$ are negative and significant and point to an impact of reorganization of about -3%. Adding (dropping) layers leads to an decrease (increase) in revenue-based TFP of around 3%.[30] Interestingly enough, and parallel to the quantity-based TFP analysis, downward transitions seem to be characterized by somewhat larger effects than upward transitions. The differences here are somewhat more pronounced, though.

Table 7: Revenue-based TFP. OLS estimator with product fixed effects.

VARIABLES	(1) Increasing	(2) Decreasing	(3) Constant	(4) All
RTFP t-1	0.925^a	0.940^a	0.955^a	0.943^a
	(0.017)	(0.021)	(0.017)	(0.011))
Change in layers	-0.023^a	-0.032^a		-0.027^a
	(0.006)	(0.006)		(0.003)
Demand t-1	-0.019^a	-0.018^a	-0.025^a	-0.020^a
	(0.004)	(0.003)	(0.003)	(0.003)
Price t-1	0.010^c	0.005	0.019^a	0.012^a
	(0.005)	(0.005)	(0.007)	(0.004)
Log Markup	0.484^a	0.434^a	0.553^a	0.486^a
	(0.043)	(0.044)	(0.059)	(0.036)
Capital	0.004^b	0.003	0.005^b	0.004^a
	(0.002)	(0.003)	(0.002)	(0.001)
Constant	0.237^a	0.095^c	-0.704^a	0.707^a
	(0.046)	(0.051)	(0.153)	(0.057)
Observations	4,141	2,829	3,031	10,001
Adjusted R^2	0.851	0.844	0.882	0.860

Firm-level clustered standard errors in parentheses. Year and Industry dummies are included in the estimations. ^{a} p<0.01, ^{b} p<0.05, ^{c} p<0.1

[30] We use the term TFP (total factor productivity) and the term 'productivity' as synonymous throughout the text. For brevity, sometimes we also refer to quantity-based productivity and revenue-based productivity as QTFP and RTFP, respectively.

5.3.2 IV

In order to estimate (21) we need to deal with the same two issues we dealt with in the case of quantity-based productivity. Now, however, in addition to finding an instrument for ΔL_{it}, we have to instrument for $\ln(\mu_{it})$ in X_{it} which is endogenous according to our assumptions. Our solution strategy is to use the same set of instruments for $\ln(\mu_{it})$, namely, demand, λ_{it-1}, and markups, μ_{it-1}, at time $t-1$, number of layers, revenue and quantity in $t-1$, productivity at time $t-2$, capital at time t, as well as all of these variables lagged to the first available year. As we did for quantity-based productivity here we use a full set of firm-product-sequence fixed effects.

Table 8 reports the results obtained using the same Dynamic Panel Data system GMM estimator used above. The results portrait a picture very similar to the one emerging from the OLS results in Table 7. While the effect of changing layers is now a bit smaller across the board, it is negative and significant in all specifications. Table 8 indicates again that decreasing the number of layers has a larger impact on productivity than adding layers. The overall causal effect of adding a layer is around -3%.

Table 8: Revenue-based TFP. Dynamic panel data estimator results with firm-product-sequence fixed effects.

	(1)	(2)	(3)	(4)
VARIABLES	Increasing	Decreasing	Constant	All
RTFP t-1	0.935[a]	0.956[a]	0.967[a]	0.953[a]
	(0.014)	(0.019)	(0.016)	(0.009)
Change in layers	-0.018[b]	-0.035[a]		-0.025[a]
	(0.008)	(0.011)		(0.009)
Demand t-1	-0.006	-0.008[a]	-0.008[c]	-0.006[a]
	(0.003)	(0.002)	(0.004)	(0.002)
Price t-1	-0.007	-0.011[c]	-0.001	-0.006[c]
	(0.005)	(0.006)	(0.006)	(0.003)
Log Markup	0.075	0.059	0.074	0.049
	(0.070)	(0.046)	(0.081)	(0.042)
Capital	0.001	0.002	0.001	0.001
	(0.002)	(0.002)	(0.002)	(0.001)
Constant	-0.027[a]	0.079	0.000	-0.014[b]
	(0.009)	(0.051)	(0.000)	(0.006)
Observations	4,141	2,829	3,031	10,001
Number of fixed effects	1,663	1,274	1,290	4,227
AR(2) Test Stat	0.043	1.352	1.548	1.805
P-value AR(2)	0.966	0.177	0.122	0.071

Firm-level clustered standard errors in parentheses. Year and Industry dummies are included in the estimations. [a] $p<0.01$, [b] $p<0.05$, [c] $p<0.1$

5.4 A Case Study: Textile and Apparel

As a final attempt to identify a causal effect of reorganization, we now use the textile sector as an example of an industry that experienced an exogenous shock. The shocks we study are the changes in quotas applied to the Textile and Apparel industry associated to China's entry into the WTO. We use the data on reductions in quotas across sub-industries and follow the methodology in Bloom, Draca, and Van Reenen (2016). The underlying identifying assumption of this strategy is that unobserved demand/technology shocks are uncorrelated with the strength of quotas to non-WTO countries (like China) in 2000. This is reasonable since these quotas were built up from the 1950s, and their phased abolition negotiated in the late 1980s was in preparation for the Uruguay Round.

To measure the degree of exposure to the quota removal we compute, for each 6-digit Prodcom product category p, the proportion of the more detailed 6-digit HS products that were covered by a quota, weighting each HS6 product by its share of EU15 imports over the period 1995-1997. Call this $QuotaCoverage_p$. Then, for each firm-product i, where by a firm-product we mean a 2 digit Prodcom code-firm combination as in the rest of the analysis, we measure the level of exposure to the quota as a weighted average, where weights are the initial shares of products p for a particular firm-product i, of $QuotaCoverage_p$. We label this variable $QuotaCoverage_i$, and focus on the relevant period 2000-2005.

We estimate the specification

$$\tilde{a}_{it} = \delta_t + \phi_a \tilde{a}_{it-1} + \phi_L \Delta L_{it} + \nu_{ait}, \tag{24}$$

where δ_t is a time fixed effect. Note that there is no product fixed-effect since we are only conditioning on firms in the Textile and Apparel industry. We estimate the regression using OLS and instrumental variable (IV) estimators. The IV specification for quantity-based TFP uses the variable $QuotaCoverage_i$ as an instrument. Note that since $QuotaCoverage_i$ is time-invariant, it precludes us from using firm-product-sequence fixed effects. We are interested in events occurring in the relevant time frame 2000-2005 only, so we lump together all of the available sequences. We obtain our set of instruments from a fourth-order polynomial in $QuotaCoverage_i$ and the lagged number of layers. We present the first stage in Appendix E.

The revenue-based TFP specifications is given by

$$\bar{a}_{it} = \bar{\delta}_t + \bar{\phi}_a \bar{a}_{it-1} + \bar{\phi}_L \Delta L_{it} + \bar{\phi}_R X_{it} + \nu_{\bar{a}it}, \tag{25}$$

where, as before, $X_{it} = [\lambda_{it-1}, p_{it-1}, \ln(\mu_{it}), k_{it}]$, and $\bar{\delta}_t$ is a time fixed effect. Again, we drop the product fixed effect since we analyze only one industry. We instrument ΔL_{it} and $\ln(\mu_{it})$ with a fourth-order polynomial in $QuotaCoverage_i$ and the lagged number of layers.

Table 9 reports the results. We find that firms that reduce layers exhibit a reduction in quantity-based productivity (significant at 1% for the OLS and IV) and an increase in revenue-based productivity (although the results are not significant). The results on quantity-based productivity are consistent with the main claim of our paper, significant, and quite large. When focusing on the firms that experienced the shock, the IV results show that in this industry reducing a layer reduces quantity-based productivity by 14%. Without instrumenting we find that these results are dampened, as we would expect in the presence of reverse causality. The results are also larger than for the whole manufacturing sector. This might be the

Table 9: Textile and Apparel: OLS and IV estimates.

VARIABLES	(1) Revenue TFP, OLS	(2) Revenue TFP, IV	(3) Quantity TFPQ, OLS	(4) Quantity TFP, IV
RTFP t-1	0.834^{a}	0.827^{a}		
	(0.040)	(0.042)		
QTFP t-1			0.865^{a}	0.864^{a}
			(0.030)	(0.030)
Change in layers	-0.014	-0.026	0.085^{a}	0.147^{b}
	(0.014)	(0.018)	(0.028)	(0.066)
Demand t-1	-0.011^{a}	-0.008^{a}		
	(0.002)	(0.003)		
Price t-1	0.004	0.002		
	(0.008)	(0.008)		
Log Markup	0.145^{a}	0.097^{c}		
	(0.033)	(0.058)		
Capital	0.003^{c}	0.002		
	(0.002)	(0.002)		
Constant	-0.077^{b}		0.019	
	(0.033)		(0.027)	
Observations	554	554	554	554
Adjusted R^2	0.666	0.660	0.729	0.725
Kleibergen-Paap stat.		32.50		42.03

Firm-product-level clustered standard errors in parentheses. Year dummies are included in the estimations. ^{a} p<0.01, ^{b} p<0.05, ^{c} p<0.1

result of the tighter identification of the shock, or of the particular characteristics of the textile sector. Firms in the textile sector are larger and more labor intensive than firms in the rest of manufacturing.

In sum, throughout our investigation we did not find any significant evidence to falsify the hypothesis proposed by the knowledge-based hierarchy model. All the significant evidence is line with its predictions. Hence, we conclude that when firms receive an exogenous shock that makes them reorganize, both quantity-based and revenue-based productivity are significantly affected.

6 Additional Results

6.1 The Effect of Organization on Prices

As we have emphasized, the main difference between the impact of a reorganization on revenue-based and quantity-based productivity is its effect on prices. Therefore, one obvious reaction is to try to look directly at the effect of reorganizations on prices. While it is important to note that we do not actually observe prices in our data –we have information on quantities sold and related revenues– we can still construct unit values (revenue over quantity) in lieu of actual prices and study how they change as firms reorganize.

Using unit values as a measure of prices to measure relative changes in revenue and quantity-based productivity could be problematic since any measurement error in quantity and/or revenue will add up into this residual measure of prices. With this caveat in mind, we can measure the effect of a firm's reorganization on our measure of prices by estimating the non-structural price equation,

$$p_{it} = b_{1,i} + b_{2,t} + b_p p_{it-1} + b_L \Delta L_{it} + u_{it}, \tag{26}$$

where the dependent variable is the log price p_{it}, computed as the difference between revenue-based TFP $\bar{a}_{it}$ and quantity-based TFP $\tilde{a}_{it}$. We also include firm-product-sequence fixed effects $b_{1,i}$ and time fixed effects $b_{2,t}$. We instrument ΔL_{it} as we did before.

Table 10: Prices. Dynamic panel data estimator results with firm-product-sequence fixed effects.

VARIABLES	(1) Increasing	(2) Decreasing	(3) Constant	(4) All
Price t-1	0.878^{a}	0.851^{a}	0.905^{a}	0.882^{a}
	(0.012)	(0.021)	(0.017)	(0.009)
Change in layers	-0.059^{a}	-0.074^{a}		-0.074^{a}
	(0.015)	(0.021)		(0.015)
Constant	0.162^{b}	-0.060	-0.383^{b}	-0.001
	(0.067)	(0.067)	(0.152)	(0.005)
Observations	4,141	2,829	3,031	10,001
Number of fixed effects	1,663	1,274	1,290	4,227
AR(2) Test Stat	0.940	-0.395	1.833	1.354
P-value AR(2)	0.347	0.693	0.067	0.176

Firm-level clustered standard errors in parentheses. Year and Industry dummies are included in the estimations. ^{a} p<0.01, ^{b} p<0.05, ^{c} p<0.1

Table 10 reports estimations using the Arellano and Bover (1995) estimator. We find that the results using prices are consistent with our main results, i.e. firms that increase (decrease) layers reduce (increase) their prices.[31]

6.1.1 Cost Pass-through Conditional on Reorganization

One way to think about the price responses implied by our results above is through the pass-through of a change in cost into prices. A simple calculation taking the responses of revenue-based and quantity-based productivity to a change in layers delivers a cost pass-through that is above one.[32] This number might seems high relative to other studies of cost pass-through that in general find values between 0.6 and 0.9. However, note that this calculation measures the cost pass-through conditional on a reorganization. This conditional pass-through has never been estimated before and so has no direct counterpart in the literature.

[31] Of course, we could use a similar reduced form approach to run identical regressions for all three variables of interest, namely, quantity-based and revenue-based productivity as well as prices. This estimation leads to very similar results to the ones in the main text. In this case, by construction, the effect of change in layers on revenue-based productivity is simply the sum of the effect of a change in layers on quantity-based productivity plus the effects on prices.

[32] For instance; take the elasticity of a change in RTFP to a change in layers, -0.025 (fourth column from Table 8) and the elasticity of a change in QTFP to a change in layers, 0.062 (fourth column from Table 6) and note that the implied response to prices is -0.088 which is 1.4 times larger than the change in costs. The response is 1.2 times larger if we use the results in the fourth column of Table 10.

In order to compare the cost pass-through into prices in our data to the estimations in the literature, we need to instead calculate an unconditional measure. In doing so, we follow two approaches.

First, we use Portuguese trade data to study the effect of exchange rate shocks on export behavior of multi-product firms, following the recent approach of Chatterjee, Dix-Carneiro, and Vichyanond (2013). We find an import price elasticity to the real exchange rate of 0.85, which is very close to what that study finds for Brazil. Berman, Martin, and Mayer (2012) find 0.83 with firm-level French data, while Campa and Goldberg (2010) find 0.64 with country- and industry-level OECD data. Therefore, our findings for this period in Portugal are clearly in line with the literature.

These results use export prices and not the Prodcom-based prices we use in our main analysis. So, as an additional exercise, we compute the price response of changes in quantity-based productivity (obtained using the procedure in our main exercise). We find almost identical elasticities with respect to cost changes (we can do the estimation separately for multiproduct and single product firms and find price elasticities to quantity-based productivity of 0.81 and 0.64 respectively, exactly in line with the literature).

Why do we obtain results that seem to suggest large pass-through? The key is that our results are not measuring average responses of prices to changes in costs or demand. They are measuring changes in prices (or revenue-based productivity) conditional on changes in layers. That is, a cost or demand shock can be quite small, but it might trigger a reorganization since the firm was right at the threshold that determines the decision to reorganize. The reorganization then changes the firm size substantially which results in a large change in prices (as we argue in the main text). As a result, the associated pass-through will seem too large because the original shock was small relative to the change in prices due to the reorganization (even the augmented shock, once we take into account the endogenous effect on quantity-based productivity of the reorganization, will seem small). Given that the literature has only calculated average pass-throughs without conditioning on shocks that trigger a reorganization, our results are not directly comparable with the literature and predictably somewhat larger. However, as we discussed above, once we calculate the unconditional pass-through we obtain exactly the same numbers others have computed.

6.2 Aggregate Productivity Effects from Reorganization

The results in the previous Section indicate that reorganizations lead to large changes in quantity-based productivity for a firm. If we want to gauge the importance of organization for aggregate productivity dynamics, we need to understand how important is the effect of reorganizations for the average firm that reorganizes. So, for the firms that reorganize we want to ask how important is the change in productivity that resulted from the reorganization, compared to changes in productivity due to shocks, or the mean reversion implied by the process in (10).

Consider a firm i that we observe from $t-T$ to t. Iterating over equation (10) we obtain that

$$\tilde{a}_{it} - \tilde{a}_{it-T} = \sum_{v=0}^{T-1} \phi_a^v \left(\alpha_i + \delta_{t-v}\right) + \left(\phi_a^T - 1\right) \tilde{a}_{it-T} + \phi_L \sum_{v=0}^{T-1} \phi_a^v \Delta L_{it-v} + \sum_{v=0}^{T-1} \phi_a^v \nu_{ait-v}.$$

Hence, the overall change in productivity for a firm, given by $\tilde{a}_{it} - \tilde{a}_{it-T}$, can be decomposed into three components. The first term is the compounded set of fixed effects. The second term is a mean reversion component that is negative when $\tilde{a}_{it-T}$ is positive since $\phi_a < 1$. Namely, productivity tends to revert to its long term mean given the number of layers. The cumulative change in productivity due to a reorganization, the term of interest, is given by the third term, namely, $\phi_L \sum_{v=0}^{T-1} \phi_a^v \Delta L_{it-v}$. The fourth term is just the accumulated effect of past shocks. Note that, because of mean-reversion, the third and fourth component explain more than 100% of the overall change in productivity. We now explore how large is the third term, the change in productivity due to a reorganization, relative to the total.

We calculate these terms for firms that increase and decrease the number of layers between $t - T$ and t. Using our results for ϕ_L and ϕ_a from column 4 of Table 6 we calculate each of these terms for the whole distribution of firms. Clearly, the actual change in productivity across firms is very heterogeneous. Some firms that add layers experiment a large decline in productivity, while some experiment a very large increase. Hence, we order firms by their overall change in productivity and in Table 11 present the distribution of the overall changes in productivity and the change in productivity due to changes in layers.[33] Columns two and three present the results for firms that increase layers, while columns four and five present the results for firms that drop layers.

Table 11: Change in Quantity TFP due to Reorganization

	Firms that increase layers		Firms that reduce layers	
Percentiles	Overall change	Due to reorganization	Overall change	Due to reorganization
10%	-0.483	0.042	-0.523	-0.093
25%	-0.179	0.051	-0.272	-0.062
50%	0.055	0.056	-0.034	-0.062
75%	0.318	0.062	0.200	-0.053
90%	0.673	0.100	0.517	-0.047
Mean	0.066	0.062	-0.019	-0.063
Observations	810	810	465	465

The results are stark. On average, or for the median firm, the increase in productivity due to reorganization explains more than the total increase in overall mean productivity. This is clearly not the case for all firms, some of them receive large positive or negative productivity shocks that account for most of the changes in productivity, but on average those shocks (and the associated reversion to the mean) contribute to more than the aggregate mean variation. The result is that reorganization can account for an increase in quantity-based productivity, when firms reorganize by adding layers, of about 6.3% while the average increase in productivity for these firms was 6.6%. Similarly, when firms reduce the number of layers, reorganization accounts for a 6.3% decrease in quantity-based productivity while the average decrease in productivity for these firms was about 2%. Reorganization accounts for more than 100% of the overall change in productivity of expanding and downsizing firms! These results underscore the importance of the

[33] The unit of observation is actually a firm-product and we allow $t - T$ and T to vary across firm-product pairs.

reorganization of firms as a source of aggregate productivity gains in the economy.

7 Conclusion

Large firm expansions involve lumpy reorganizations that affect firm productivity. Firms that reorganize and add a layer increase hours of work by 25% and value added by slightly more than 3%, while firms that do not reorganize decrease hours slightly and value added by only 0.1%. Reorganization therefore accompanies firms' expansions. A reorganization that adds layers allows the firm to operate at a larger scale. We have shown that such a reorganization leads to increases in quantity-based productivity of about 6%. Even though the productive efficiency of the firm is enhanced by adding layers, its revenue-based productivity declines by around 3%. The new organizational structure lowers the marginal cost of the firm and it allows it to increase its scale. This makes firms expand their quantity and move down their demand curves, thereby lowering prices and revenue-based productivity.

We use a detailed data set of Portuguese firms to show that these facts are very robustly present in the data. Our data set is somewhat special in that it not only includes employer-employee matched data, necessary to built a firm's hierarchy, but it also includes information on quantity produced. This allows us to contrast the effect of reorganization, using fairly flexible methodologies, to calculate quantity and revenue-based productivity. Furthermore, given that we have a relatively long panel, we show that the results hold using a large number of fixed effects on top of time and industry dummies. We do not find any case in which the evidence significantly falsifies the main hypothesis of the effect of a reorganization on both types of firm productivity. In contrast, we present significant evidence of a causal effect of an increase in layers on both revenue-based and quantity-based productivity.

Our findings underscore the role that organizational decisions play in determining firm productivity. Our results, however, can be viewed more broadly as measuring the impact of lumpy firm level changes on the endogenous component of firm productivity. Many changes that increase the capacity of the firm to grow (like building a new plant or production line, or creating a new export link with a foreign partner) will probably result in similar effects on quantity and revenue-based productivity. In our view, the advantage of looking at reorganizations using a firm's management layers, as defined by occupational classifications, is that firms change them often and in a very systematic way. Furthermore, this high frequency implies that many of the observed fluctuations in both quantity-based and revenue-based productivity result from these endogenous firm decisions and should not be treated as exogenous shocks to the firm.

We also provide new evidence on how firms change prices conditional on changes in layers. These results relate to a large body of literature trying to underscore the magnitude of cost pass-through into prices. While our conditional results are larger than the ones found in this literature, once we calculate the unconditional pass-through we obtain exactly the same numbers others have computed in similar datasets. Hence, conditioning on whether or not a firm has reorganized is important to understand the pricing decisions of firms.

Recognizing that part of a firm's productivity changes are endogenous is relevant because the ability of firms to change their organization might depend on the economic environment in which they operate. We have shown that changing the number of management layers is important for firms to realize large productivity gains when they grow. Environments in which building larger hierarchies is hard or costly due, for example, to the inability to monitor managers or to enforce detailed labor contracts prevent firms from obtaining these productivity gains.[34] This, among other factors, could explain why firms in developing countries tend to grow less rapidly (Hsieh and Klenow, 2014).

[34] See Bloom et al. (2013) for some evidence on potential impediments in India.

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Appendix

A Additional Details about Data, Tables and Figures

We start with the matched employer-employee data set, keeping only firms in the manufacturing sector located in mainland Portugal and dropping firms with non-positive sales. Information for the year 2001 for the matched employer-employee data set was only collected at the firm-level. Given that worker-level variables are missing in 2001 we have to drop all firm-level observations for 2001. There are in total 353,311 firm-year observations. We then focus on the worker-level information and drop a minority of workers with an invalid social security number and with multiple jobs in the same year. We further drop worker-year pairs whenever (i) their monthly normal or overtime hours are non-positive or above 480; (ii) the sum of weekly normal and overtime hours is below 25 and above 80; (iii) their age is below 16 and above 65 years; (iv) they are not full-time employees of the firm. Based on the resulting sample, we trim worker-year pairs whose monthly wage is outside a range defined by the corresponding year bottom and top 0.5 percentiles. This leaves us with 321,719 firm-year and 5,174,324 worker-year observations. In the analysis, we focus on manufacturing firms belonging to NACE rev.1 2-digits industries between 15 and 37, excluding 16 "Manufacture of tobacco products", 23 "Manufacture of coke, refined petroleum products and nuclear fuel", 30 "Manufacture of office machinery and computers", and 37 "Recycling", due to confidentiality reasons.

We then turn to the balance sheet data set and recover information on firms' operating revenues, material assets, costs of materials, and third-party supplies and services. We compute value-added as operating revenues minus costs of materials and third-party supplies and services. We drop firm-year pairs with non-positive value-added, material assets, cost of materials, and size. This reduces the size of the overall sample to 61,872 firm-year observations and 2,849,363 worker-year observations.

Finally, we turn to the production data set and recover information on firm-product sales and volume for each firm-product-year triple in the data set. In the production data set a product is identified by a 10-digits code, plus an extra 2-digits that are used to define different variants of the variable.[35] The first 8 digits correspond to the European PRODCOM classification while the additional two have been added by INE to further refine PRODCOM. The volume is recorded in units of measurement (number of items, kilograms, liters) that are product-specific while the value is recorded in current euros. We drop observations where the quantity produced, quantity sold, and sales are all zero. For each product-firm-year combination, we are able to compute a unit value. We adjust the quantity sold, for each firm-year-product, by multiplying it by the average (across firms) product-year unit value. We then construct a more aggregate partition of products based on the first 2-digits as well as on the unit of measurement. More specifically, we assign 10-digits products sharing the same first 2 digits and unit of measurement to the same aggregate product. We keep only manufacturing products, and aggregate quantity sold and sales at the firm-year-product level following the new definition of a product. We restrict the analysis to products with at least 50 firm-year observations. Finally, we merge the production data with the matched employer-employee and firm balance sheet data.

[35] From the raw data it is possible to construct different measures of the volume and value of a firm's' production. For the sake of this project we use the volume and value corresponding to a firms' sales of its products. This means we exclude products produced internally and to be used in other production processes within the firm as well as products produced for other firms, using inputs provided by these other firms. The advantage of using this definition is that it nicely corresponds to the cost of materials coming from the balance sheet data.

Given that we restricted the set of products considered in the analysis, we compute the ratio between total firm-year sales in the sample coming from the production data set and firm-year sales in the firm balance sheet sample and drop firm-year pairs we extreme values of the ratio (below 25 percent and above 105 percent). We then adjust firm sales (from the balance sheet data), cost of materials, material assets, wage bill, size, value-added, wage bill of layer zero, and number of employees in layer zero using the above sales ratio. We then split the same set of variables into parts associated with each product, using the product sales in the production data set. We trim firm-year-product triples that do not satisfy one or more of the following constraints: the sum of cost of materials and wages, as a share of sales, below one; unit value between the 1st and 99th percentiles; cost of materials as a share of sales between the 1st and 99th percentiles; ratio of material assets to size between the 1st and 99th percentiles. The size of the sample is now 19,031 firm-year observations and 1,593,294 worker-year observations.

Even after this significant—but necessary to accommodate the more stringent requirements of TFPQ—reduction in the coverage of the data, our sample of firms still covers about 43 percent (49 percent when the reference population is firms with at least 20 employees) of aggregate manufacturing sales, and 31 percent (40 percent when the reference population is firms with at least 20 employees) of aggregate manufacturing employment.

Table A.1: Classification of Workers According to Hierarchical Levels

Level	Tasks	Skills
1. Top executives (top management)	Definition of the firm general policy or consulting on the organization of the firm; strategic planning; creation or adaptation of technical, scientific and administrative methods or processes	Knowledge of management and coordination of firms fundamental activities; knowledge of management and coordination of the fundamental activities in the field to which the individual is assigned and that requires the study and research of high responsibility and technical level problems
2. Intermediary executives (middle management)	Organization and adaptation of the guidelines established by the superiors and directly linked with the executive work	Technical and professional qualifications directed to executive, research, and management work
3. Supervisors, team leaders	Orientation of teams, as directed by the superiors, but requiring the knowledge of action processes	Complete professional qualification with a specialization
4. Higher-skilled professionals	Tasks requiring a high technical value and defined in general terms by the superiors	Complete professional qualification with a specialization adding to theoretical and applied knowledge
5. Skilled professionals	Complex or delicate tasks, usually not repetitive, and defined by the superiors	Complete professional qualification implying theoretical and applied knowledge
6. Semi-skilled professionals	Well defined tasks, mainly manual or mechanical (no intellectual work) with low complexity, usually routine and sometimes repetitive	Professional qualification in a limited field or practical and elementary professional knowledge
7. Non-skilled professionals	Simple tasks and totally determined	Practical knowledge and easily acquired in a short time
8. Apprentices, interns, trainees	Apprenticeship	

Notes: Hierarchical levels defined according to Decreto Lei 121/78 of July 2nd (Lima and Pereira, 2003).

All monetary values are deflated to 2005 euros using the monthly (aggregated to annual) Consumer Price Index (CPI - Base 2008) by Special Aggregates from Statistics Portugal. Monthly wages are converted to annual by multiplying by 14.

In order to construct our firm level exchange rate shock, we follow Bertrand (2004), Park et al. (2010) and Revenga (1992). Nominal exchange rates and consumer price indexes data come from the International Financial Statistics (IFS) dataset provided by the International Monetary fund and refer to the period 1995-2005. Using this data along with firm-level information on exports and imports across countries we construct two firm-time specific instruments; one based on firm-exports and one based on firm-imports.

We start by computing the log real exchange rate between Portugal (h) and any other country (k) at time t using the formula:

$$\log(RER_{kt}) = \log\left(\frac{e_{hkt}}{CPI_{ht}/CPI_{kt}}\right)$$

where the nominal exchange rate (e_{hkt}) is defined as units of home currency per unit of k currency at time t while CPI_{ht} and CPI_{kt} are the consumer price indexes of Portugal and country k respectively.

In the case of the export IV we look at the portfolio of destinations k served by firm i at time $t-1$ and compute export shares for each destination k: EX_s_{ikt-1}. We then use such shares to aggregate $\log(RER_{kt})$ at time t across countries to obtain a firm-time specific log real exchange rate:

$$\log(EX\_RER_{it}) = \sum_k EX\_s_{ikt-1} \log(RER_{kt})$$

We construct a similar instrument using information on import origins shares: $\log(IM\_RER_{it})$. Note that the level of $\log(EX\_RER_{it})$ and $\log(IM\_RER_{it})$ does not mean much per se. What does have a precise meaning is the time change within a firm which indicates whether there has been an overall appreciation or a depreciation of the real exchange rate faced by a particular firm on the export and import markets. Consequently, we use the change between $t-1$ and t of $\log(EX\_RER_{it})$ and $\log(IM\_RER_{it})$ as instruments in t. To be precise, we use the product of these change and the export or import intensity of the firm (exports over turnover or imports over inputs expenditure) in $t-1$ as an instrument. The export-based appreciation or depreciation is meant to capture shocks to a firm's demand while import-based appreciation or depreciation proxies for cost shocks.

Some concepts are recurring in the explanation of a majority of the tables and figures. We define them here and consider them understood in main text:

- **Product**. In the production dataset a product is identified by a 10-digits code, plus an extra 2-digits that are used to define different variants of the variable. In the analysis, in order to have enough observations, we aggregate products at the "2-digits - same unit of measurement" level. We keep only manufacturing products, and aggregate quantity sold and sales at the firm-year-product level following the new definition of a product. We restrict the analysis to products with at least 50 firm-year observations.

- **Layer number.** In the matched employer-employee data set, each worker, in each year, has to be assigned to a category following a (compulsory) classification of workers defined by the Portuguese law (see Table A.1 and Mion and Opromolla, 2014). Classification is based on the tasks performed and skill requirements, and each category can be considered as a level in a hierarchy defined in terms of increasing responsibility and task complexity (*qualif*). On the basis of the hierarchical classification and taking into consideration the actual wage distribution, we partition the available categories into occupations. We assign "Top executives (top management)" to occupation 3; "Intermediary executives (middle management)" and "Supervisors, team leaders" to occupation 2; "Higher-skilled professionals" and some "Skilled professionals" to occupation 1; and the remaining employees, including "Skilled professionals", "Semi-skilled professionals", "Non-skilled professionals", and "Apprenticeship" to occupation 0. The position of the workers in the hierarchy of the firm, starting from 0 (lowest layer, present in all firms) to 3 (highest layer, only present in firms with 3 layers of management).

- **Number of layers of management.** A firm reporting c occupational categories will be said to have $L = c - 1$ layers of management: hence, in our data we will have firms spanning from 0 to 3 layers of management (as in CMRH). In terms of layers within a firm we do not keep track of the specific occupational categories but simply rank them. Hence a firm with occupational categories 2 and 0 will have 1 layer of management, and its organization will consist of a layer 0 corresponding to some skilled and non-skilled professionals, and a layer 1 corresponding to intermediary executives and supervisors.
- **Reorganization in year t.** A firm reorganizes in year t when it changes the number of management layers with respect to those observed in the most recent prior available year (year $t-1$ in most cases).
- **Year of the first observed reorganization for a firm.** The earliest reorganization year observed (for those firms first appearing in the data prior to 1997) or the first year in which a firm appears in the data (for those firms first appearing in the data in 1997 or later).
- **Firm industry.** The industry of the firm is measured according to the NACE rev.1 2-digits disaggregation. This includes 19 divisions, from division 15 (Manufacture of food products and beverages) to division 36 (Manufacture of furniture; manufacturing n.e.c.). We drop division 16 (Manufacture of tobacco products), 23 (Manufacture of coke, refined petroleum products and nuclear fuel), and 30 (Manufacture of office machinery and computers) because they comprise very few observations.
- **Wage bill.** A worker annual wage is computed adding the monthly base and overtime wages plus regular benefits and multiplying by 14. We apply a trimming of the top and bottom 0.5 per cent within each year. A firm wage bill is the sum of the annual wages of all its workers that satisfy the criteria listed above.
- **Hours**. These include both regular and overtime hours. We drop worker-year pairs whenever the number of monthly regular or overtime hours is higher than 480, and whenever total hours per week are lower than 25 or higher than 80.
- **Material expenditures**. This corresponds to the cost of the goods sold and materials consumed, plus the cost of external supplies and services, as recorded in the firm's balance sheet.
- **Capital**. This corresponds to the gross value of tangible assets as recorded in the firm's balance sheet.
- **Revenues and quantities**. We use the volume and value from the production dataset corresponding to a firm's sales of its products. This means that we exclude products produced internally and to be used in other production processes within the firm as well as products produced for other firms, using inputs provided by these other firms.
- **Value-added**. Revenues minus material expenditures.

All monetary values are deflated to 2005 euros using the monthly (aggregated to annual) Consumer Price Index (CPI - Base 2008) by Special Aggregates from Statistics Portugal. Monthly wages are converted to annual by multiplying by 14, the number of payments per year in Portugal.

A.1 Tables and Figures Description

Table 1: This table describes the organization of a firm producing "Knitted and crocheted pullovers, cardigans, and similar articles" (Nace1772) in 2004, when the firm had three layers of management, and in 2005,

when the firm only has two layers of management. The table reports the number of workers by ISCO-88 1-digit major groups (on the rows) and layer number (on the columns).

Table 2: This table describes the organization of a firm producing "Woven fabrics" (Nace 1720) in 1999, when the firm had three layers of management, and in 2000, when the firm only has two layers of management. The table reports the number of workers by ISCO-88 1-digit major groups (on the rows) and layer number (on the columns).

Table 3: This table describes the organization of a firm producing "Women's town footwear with leather uppers" (Nace 19301352) in 1998, when the firm had three layers of management, and in 1999, when the firm only has two layers of management. The table reports the number of workers by ISCO-88 1-digit major groups (on the rows) and layer number (on the columns).

Table 4: This table describes the organization of a firm producing "Manufacture of articles of cork, straw and plaiting materials" (Nace 2052) in 2004, when the firm only had one layer of management, and in 2005, when the firm had two layers of management. The table reports the number of workers by ISCO-88 1-digit major groups (on the rows) and layer number (on the columns).

Table 5: The data underlying Table 5 is composed of sequences of firm-product-years with either one or zero changes in layers. For a given product, we define a firm sequence of type $L0$ as the series of years in which a firm sells the corresponding product and has the same consecutively observed number of management layers L plus the adjacent series of years in which a firm sells the product and has the same consecutively observed number of management layers $L0$. For example, a firm that we observed selling the product all years between 1996 and 2000 and that has zero layers in 1996, 1997, and 2000 and one layer in 1998 and 1999 would have two sequences: An (increasing) 0-1 sequence (1996 to 1999) as well as a (decreasing) 1-0 sequence (1998 to 2000). Firms that never change layers in our sample form a constant- layer sequence. We group firm-product sequences into "Increasing", "Decreasing", and "Constant" sequence types.

For each type of sequence, Table 5 shows estimates of OLS regressions where the dependent variable is our measure of quantity-based productivity, described in Section 4, in a given year. The key regressor is the change in the number of management layers in the firm in year t. We control for quantity-based productivity in the previous year, and include a set of year and industry dummies. Firm-level clustered standard errors are in parentheses. The last column of Table 5 shows estimates of a regression that pools all types of sequences.

Table 6: Table 6 shows estimates of the same type of regressions described for Tables 5 while allowing for firm-product-sequence fixed effects. Instead of OLS we employ the system GMM estimator proposed by Arellano and Bover (1995) within the context of dynamic panel data with endogenous regressors. We implement this with the xtabond2 command in Stata. We use for the levels equation demand and markups at time t-1, number of layers, revenue and quantity in t-1, productivity in t-2, capital at time t as well as all these variables lagged to the first available year. All of these variables meet the requirements of good instruments under the assumptions of our model. We also use all suitable lags and differences of the dependent variable as "GMM-style" instruments for the first-difference and levels equations.

Table 7: The data underlying Table 7, like for Table 5, is composed of sequences of firm-product-years with either one or zero changes in layers. For each type of sequence, Table 7 shows estimates of OLS regressions where the dependent variable is our measure of revenue-based productivity, described in Section 4, in a given year. The key regressor is the change in the number of management layers in the firm in year t. We control for the previous year values of revenue-based productivity, demand shock, and price, as well as for the current value of the markup and capital, and include a set of year and industry dummies. Firm-level

clustered standard errors are in parentheses. The last column of Table 7 shows estimates of a regression that pools all types of sequences.

Table 8: Table 8 shows estimates of the same type of regressions described for Tables 7 while allowing for firm-product-sequence fixed effects. Instead of OLS we employ the system GMM estimator proposed by Arellano and Bover (1995) within the context of dynamic panel data with endogenous regressors. We implement this with the xtabond2 command in Stata. We instrument changes in layers as well as markups in this specification. We use for the levels equation demand and markups at time t-1, number of layers, revenue and quantity in t-1, revenue productivity in t-2, capital at time t as well as all these variables lagged to the first available year. All of these variables meet the requirements of good instruments under the assumptions of our model. We also use all suitable lags and differences of the dependent variable as "GMM-style" instruments for the first-difference and levels equations.

Table 9: The data underlying Table 9 is at the firm-year level and includes firms that belong to the Textile and Apparel sector (Nace 17). Table 9 shows estimates of OLS and IV regressions where the dependent variable is our measure of either revenue-based or quantity-based productivity, described in Section 4, in a given year. We apply a trimming of 0.5 percent to the bottom and top of the distribution of TFPQ. The key regressor is the change in the number of management layers in the firm in year t. In the regressions where the dependent variable is revenue-based productivity, we control for the previous year values of revenue-based productivity, demand shock, and price, as well as for the current value of the markup and capital, and include a set of year and industry dummies. In the regressions where the dependent variable is quantity-based productivity, we control for quantity-based productivity in the previous year, and include a set of year and industry dummies. For the IV specifications, the main instrument is the firm-level degree of exposure to the quota removal (QuotaCoverage), as described in Section 5. The full set of instruments includes a fourth-order polynomial in QuotaCoverage and the lagged number of layers. Firm-product-level clustered standard errors are in parentheses. Please refer to Appendix E for further details.

Table 10: Table 10 shows estimates of the same type of regressions described for Tables 6 except for the variable of interest being price instead of quantity-based productivity. We implement this with the xtabond2 command in Stata. We use for the levels equation demand and markups at time t-1, number of layers, revenue and quantity in t-1, prices in t-2, capital at time t as well as all these variables lagged to the first available year. All of these variables meet the requirements of good instruments under the assumptions of our model. We also use all suitable lags and differences of the dependent variable as "GMM-style" instruments for the first-difference and levels equations.

Table 11: Description presented in main text.

Table B-1: This table reports, for each year, the number of firms in Sample 1 and corresponding averages across all firms for selected variables. Value added, hours, and wage are defined above. Value added is in 2005 euros. Wage is average hourly wage in 2005 euros. Hours are yearly. # of layers is the average number of layers of management across firms in each year.

Table B-2: Table B-2 reports summary statistics on firm-level outcomes, grouping firm-year observations according to the number of layers of management reported (# of layers). Firm-years is the number of firm-years observations in the data with the given number of layers of management. Value added, hours, and wage are defined above. Value added in 000s of 2005 euros. Wage is either average or median hourly wage in 2005 euros. Both value added and wages are detrended. Hours are yearly.

Table B-3 and B-4: Table B-3 reports the fraction of firms that satisfy a hierarchy in hours, grouping firms by their number of layers of management (# number of layers). Hours N_L^l is the number of hours reported in layer l in an L layers of management firm. For $L = 1, 2, 3$, and $l = 0, ..., L-1$ we say that a firm satisfies a hierarchy in hours between layers number l and $l+1$ in a given year if $N_L^l \geq N_L^{l+1}$, i.e. if the number of hours worked in layer l is at least as large as the number of hours worked in layer $l+1$; moreover, we say that a firm satisfies a hierarchy at all layers if $N_L^l \geq N_L^{l+1} \quad \forall l = 0, ..., L-1$, i.e. if the number of hours worked in layer l is at least as large as the number of hours in layer $l+1$, for all layers in the firm. Following these definitions, the top panel reports, among all firms with $L = 1, 2, 3$ layers of management, the fraction of those that satisfy a hierarchy in hours at all layers (first column), and the fraction of those that satisfy a hierarchy in hours between layer l and $l+1$, with $l = 0, ..., L-1$ (second to fourth column).

Table B-4 is the same as Table B-3 for the case of wages, where w_L^l is the average hourly wage in layer l in an L layers of management firm.

Table B-5: Table B-5 reports the distribution of the number of layers of management at time $t+1$, grouping firms according to the number of layers of management at time t. Among all firms with L layers of management ($L = 0, ..., 3$) in any year from 1996 to 2004, the columns report the fraction of firms that have layers $0, ..., 3$ the following year (from 1997 to 2005), or are not present in the dataset, Exit. The table also reports, in the bottom row, the distribution of the new firms by their initial number of layers. The elements in the table sum to 100% by row.

Table B-6: This table shows changes in firm-level outcomes between adjacent years for all firms (All), and for the subsets of those that increase (Increase L), don't change (No change in L) and decrease (Decrease L) layers. It reports changes in log hours, log normalized hours, log value added, log average wage, and log average wage in common layers for the whole sample. The change in average wage for common layers in a firm that transitions from L to L' layers is the change in the average wage computed using only the $min\{L, L'\}$ layers before and after the transition. To detrend a variable, we subtract from all the log changes in a given year the average change during the year across all firms.

Table B-7: This table reports the results of regressions of log change in normalized hours by layer on log change in value added for firms that do not change their number of layers of management L across two adjacent periods. Specifically, we run a regression of log change in normalized hours at layer l (layer) in a firm with L (# of layers in the firm) layers of management on a constant and log change in value added across all the firms that stay at L layers of management across two adjacent years. Robust standard errors are in parentheses.

Table B-8: This table reports the results of regressions of log change in hourly wage by layer on log change in value added for firms that do not change their number of layers of management L across two adjacent periods. Specifically, we run a regression of log change in average hourly wage at layer l (layer) in a firm with L (# of layers in the firm) layers of management on a constant and log change in value added across all the firms that stay at L layers of management across two adjacent years. Robust standard errors are in parentheses.

Table B-9: This table shows estimates of the average log change in normalized hours and estimates of the average log change in hourly wage at each layer l (Layer) among firms that transition from L (# of layers before) to L' layers (# of layers after), with $L \neq L'$: for a transition from L to L', we can only evaluate changes for layer number $l = 0, ..., \min\{L, L'\}$. $d \ln n_{Lit}^l$ is the average log change in the transition, estimated as a regression of the log change in the number of normalized hours in layer l in two adjacent years on a constant. $d \ln w_{Lit}^l$ is the average log change in the transition, estimated as a regression of the log change in the average hourly wage in layer l in two adjacent years on a constant. Robust standard errors are in parentheses.

Table 11: : This table reports the mean, and a number of percentiles, of the distribution of the overall change in quantity TFP, as well as the component associated with a firm's reorganization, for firms that increase the number of layers and for firms that decrease the number of layers.

Figure 3: This figure reports the evolution revenue, quantity sold, and price for a single-product firm producing aluminium cookware that adds a layer of management between 1997 and 1998.

Figure 4 panel a and b: 5 panel a and b: This figure reports the log change in value-added per worker for firms that increase/decrease sales (left hand-side) and increase/decrease the number of management layers (right hand-side) by NACE 2-digits industries.

Figure B-1, B-2, and B-3: These figures report kernel density estimates of the distribution of log value added (Figure B-1), log hours worked (Figure B-2) and log hourly wage (Figure B-3) by number of layers in the firm. One density is estimated for each group of firms with the same number of layers.

B Portuguese Production Hierarchies: Facts

In this section we reproduce some of the main results in CMRH for France using our largest, but less complete, data for Portugal. Table B-1 presents some basic statistics for the largest, but less precise, sample for the ten years spanned by our data. The data exhibits some clear trends over time. In particular, the number of firms declines and firms tend to become larger. In all our regressions we control for time and industry fixed effects. These results that follow underscore our claim that the concept of layers we use is

Table B-1: Firm-level data description by year

		Mean			
Year	Firms	Value Added	Hours	Wage	# of layers
1996	8,061	1,278	102,766	4.37	1.25
1997	8,797	1,227	91,849	4.48	1.20
1998	7,884	1,397	96,463	4.81	1.28
1999	7,053	1,598	105,003	4.93	1.31
2000	4,875	2,326	139,351	5.13	1.62
2002	4,594	2,490	125,392	5.63	1.62
2003	4,539	2,363	124,271	5.65	1.70
2004	4,610	2,389	124,580	5.82	1.74
2005	3,962	2,637	129,868	6.01	1.76

Notes: Value added in 2005 euros. Wage is average hourly wage in 2005 euros.

meaningful. We show this by presenting evidence that shows, first, that firms with different numbers of layers are systematically different in a variety of dimensions; second, that firms change layers in a systematic and expected way; third, that the workforce within a layer responds as expected as firms add or subtract layers.

Table B-2: Firm-level data description by number of layers

		Mean			Median
# of layers	Firm-years	Value added	Hours	Wage	Wage
0	14,594	267.2	12,120.7	3.55	3.16
1	14,619	648.4	31,532.0	4.03	3.64
2	12,144	2,022.7	96,605.2	4.51	4.11
3	13,018	10,286.2	327,166.8	5.73	5.20

Notes: Value added in 000s of 2005 euros. Wage is either average or median hourly wage in 2005 euros. Hours are yearly.

Table B-2 presents the number of firm-year observations by number of management layers as well as average value added, hours, and wages. It also presents the median wage given that the wage distribution can be sometimes very skewed. The evidence clearly shows that firms with more layers are larger in terms of value added and hours. It also shows that firms with more layers pay on average higher wages. Figures B-1 to B-3 present the distributions of value added, employment and the hourly wage by layer. The distributions are clearly ordered. In Figure B-2 the modes in the distribution of hours corresponds to the number of hours of one full-time employee, two full-time employees, etc. The peaks presented in firms with zero number of layers corresponds to the number of hours of discrete numbers of full time workers. This is also appreciated, although to a lesser degree in firms with one management layer. For a similar depiction of how hours are distributed for firms with different number of layers please see Figure 3 in Caliendo et al. (2015). The figures show that firms with different numbers of layers are in fact very different.

Table B-3 shows that the implied hierarchical structure of firms is hierarchical in the majority of cases.

Figure B-1: Value Added Density

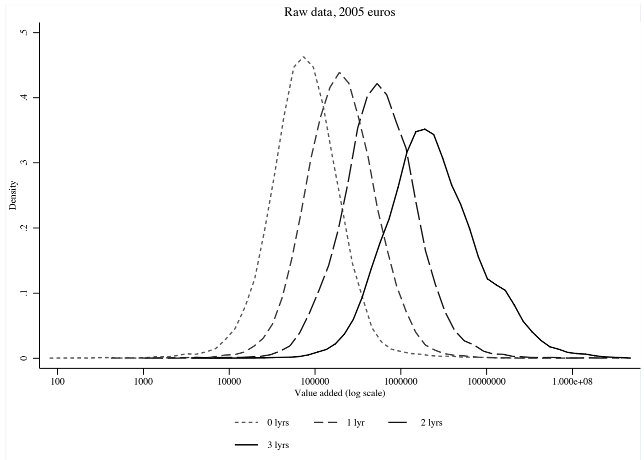

Figure B-2: Employment (Hours) Density

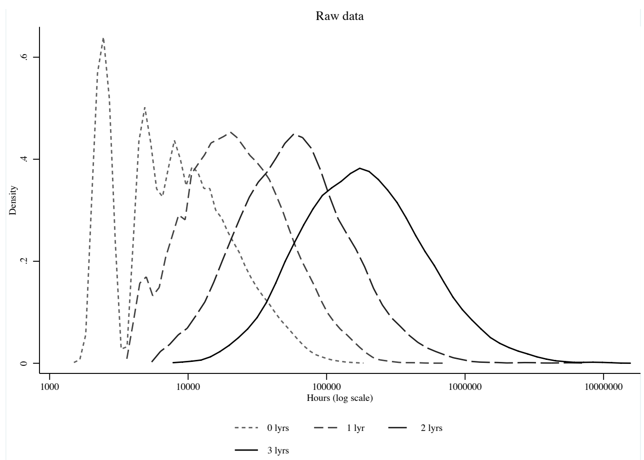

Table B-4 shows that lower layers command lower wages in the vast majority of cases. Table B-5 presents a transition matrix across layers. In Table B-6 we divide firms depending on whether they add, do not change, or drop layers, and present measured changes in the total number of hours, number of hours normalized by the number of hours in the top layer, value added, and average wages. For all these measures we present changes after de-trending in order to control for the time trends in the data that we highlighted before. Tables B-7 and B-8 present the elasticity of normalized hours (hours at each layer relative to the top layer) and wages, respectively, to value added for firms that do not add layers. The first column indicates the number of layers in the firm, and the second the particular layer for which the elasticity is calculated. Table B-9 shows changes in normalized hours and wages when firms reorganize. The tables show the total number of layers before and after the reorganization, as well as the layer for which the log-change is computed.

Figure B-3: Hourly Wage Density

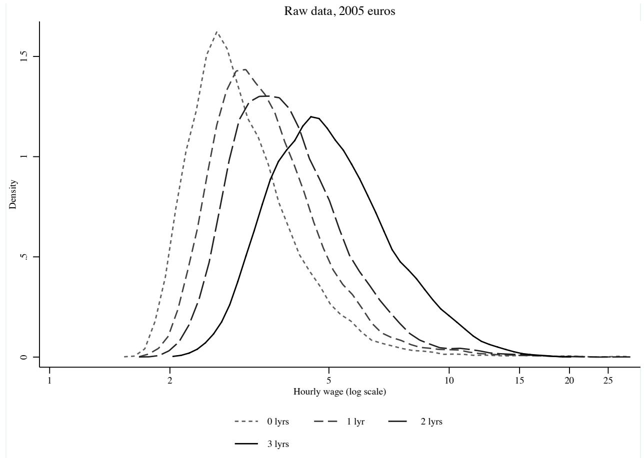

Table B-3: Percentage of firms that satisfy a hierarchy in hours

# of layers	$N_L^l \geq N_L^{l+1}$ all l	$N_L^0 \geq N_L^1$	$N_L^1 \geq N_L^2$	$N_L^2 \geq N_L^3$
1	91.64	91.64	–	–
2	69.62	92.07	77.35	–
3	50.51	88.70	74.34	83.65

N_L^l = hours at layer l of a firm with L layers.

Table B-4: Percentage of firms that satisfy a hierarchy in wages

# of layers	$w_L^l \leq w_L^{l+1}$ all l	$w_L^0 \leq w_L^1$	$w_L^1 \leq w_L^2$	$w_L^2 \leq w_L^3$
1	75.87	75.87	–	–
2	65.66	85.21	79.57	–
3	67.11	92.36	84.62	87.82

Table B-5: Distribution of layers at $t+1$ conditional on layers at t

		# of layers at $t+1$					
		Exit	0	1	2	3	Total
# of layers at t	0	31.19	54.29	12.54	1.69	0.29	100.00
	1	25.75	10.26	51.12	11.35	1.51	100.00
	2	21.73	1.49	12.06	49.62	15.09	100.00
	3	15.68	0.37	1.46	12.90	69.59	100.00
	New	85.08	5.31	3.77	3.01	2.83	100.00

Table B-6: Changes in firm-level outcomes

# of layers	All	Increase L	No Change in L	Decrease L
dln total hours	-0.0068^a	0.2419^a	-0.0080^a	-0.2992^a
- detrended		0.2472^a	-0.0011	-0.2911^a
dln normalized hours	0.0099^b	1.0890^a	-0.0204^a	-1.1043^a
- detrended		1.0761^a	-0.0299^a	-1.1128^a
dlnVA	0.0173^a	0.0509^a	0.0155^a	-0.0126^a
- detrended		0.0323^a	-0.0013	-0.0307^a
dln avg. wage	0.0369^a	0.0683^a	0.0348^a	0.0122^a
- detrended		0.0303^a	-0.0018^c	-0.0253^a
common layers	0.0356^a	0.0068^b	0.0348^a	0.0750^a
- detrended		-0.0295^a	-0.0005	0.0387^a

Notes: ^{a} p<0.01, ^{b} p<0.05, ^{c} p<0.1.

Table B-7: Elasticity of n_L^ℓ with respect to value added for firms that do not change L

# of layers	Layer	Elasticity	# observations
1	0	0.1155^a	6,351
2	0	0.1146^a	4,998
2	1	-0.0147	4,998
3	0	0.1760^a	7,079
3	1	0.0847^a	7,079
3	2	0.0987^a	7,079

Notes: Robust standard errors in parentheses: ^{a} p<0.01, ^{b} p<0.05, ^{c} p<0.1.

Table B-8: Elasticity of w_L^ℓ with respect to value added for firms that do not change L

# of layers	Layer	Elasticity	# observations
0	0	0.0056	6,987
1	0	0.0216^a	6,351
1	1	0.0283^a	6,351
2	0	0.0150^b	4,998
2	1	0.0229^b	4,998
2	2	0.0303^b	4,998
3	0	0.0225^a	7,079
3	1	0.0201^a	7,079
3	2	0.0298^a	7,079
3	3	0.0199^b	7,079

Notes: Robust standard errors in parentheses: ^{a} p<0.01, ^{b} p<0.05, ^{c} p<0.1.

Table B-9: $d\ln n^{\ell}_{Lit}$ and $d\ln w^{\ell}_{Lit}$ for firms that transition

# of layers before	# of layers after	Layer	$d\ln n^{\ell}_{Lit}$	$d\ln w^{\ell}_{Lit}$	# observations
0	1	0	1.2777[a]	0.0062	1,614
0	2	0	1.6705[a]	0.0207	218
0	3	0	2.3055[a]	-.1878[a]	37
1	0	0	-1.2304[a]	0.0557[a]	1,275
1	2	0	0.5178[a]	0.0038	1,410
1	2	1	0.4920[a]	-0.0624[a]	1,410
1	3	0	0.9402[a]	-0.0230[a]	188
1	3	1	0.8367[a]	-0.1710[a]	188
2	0	0	-1.6449[a]	0.0692[a]	150
2	1	0	-0.5645[a]	0.0373[a]	1,215
2	1	1	-0.5060[a]	0.1192[a]	1,215
2	3	0	0.6806[a]	-0.0015	1,520
2	3	1	0.7098[a]	-0.0113[b]	1,520
2	3	2	0.6340[a]	-0.0676[a]	1,520
3	0	0	-2.5187[a]	0.2673[a]	38
3	1	0	-0.9772[a]	0.0691[a]	149
3	1	1	-0.8636[a]	0.1672[a]	149
3	2	0	-0.7977[a]	0.0313[a]	1,312
3	2	1	-0.7532[a]	0.0467[a]	1,312
3	2	2	-0.6465[a]	0.1114[a]	1,312

Notes: Robust standard errors in parentheses: [a] p<0.01, [b] p<0.05, [c] p<0.1.

C Estimating Equations

C.1 Time evolution of quantity TFP

1st stage ESTIMATION Using (7) and (10) one gets

$$q_{it} = \alpha_O \left(\ln C\left(O_{it}; w_t\right) - k_{it}\right) + \alpha_M \left(m_{it} - k_{it}\right) + \gamma k_{it} + \phi_a \tilde{a}_{it-1} + \phi_L \Delta L_{it} + \tilde{\nu}_{ait}, \tag{C-1}$$

where we define $\tilde{\nu}_{ait} \equiv \delta_t + \nu_{ait}$. Substitute this expression into (8)

$$\begin{aligned} r_{it} &= \frac{\alpha_O}{\mu_{it}} \left(\ln C\left(O_{it}; w_t\right) - k_{it}\right) + \frac{\alpha_M}{\mu_{it}} \left(m_{it} - k_{it}\right) \\ &\quad + \frac{\gamma}{\mu_{it}} k_{it} + \frac{\phi_a}{\mu_{it}}\ \tilde{a}_{it-1} + \frac{\phi_L}{\mu_{it}} \Delta L_{it} + \frac{1}{\mu_{it}} \tilde{\nu}_{ait} + \frac{1}{\mu_{it}} \lambda_{it}. \end{aligned}$$

Now use $\mu_{it} = \frac{\alpha_M}{s_{Mit}}$ to obtain

$$\begin{aligned} r_{it} &= \frac{s_{Mit}\alpha_O}{\alpha_M} \left(\ln C\left(O_{it}; w_t\right) - k_{it}\right) + s_{Mit} \left(m_{it} - k_{it}\right) \\ &\quad + s_{Mit} \frac{\gamma}{\alpha_M} k_{it} + s_{Mit} \frac{\phi_a}{\alpha_M}\ \tilde{a}_{it-1} + s_{Mit} \frac{\phi_L}{\alpha_M} \Delta L_{it} + \frac{s_{Mit}}{\alpha_M} \tilde{\nu}_{ait} + \frac{s_{Mit}}{\alpha_M} \lambda_{it}, \end{aligned}$$

or

$$\begin{aligned} r_{it} - \frac{s_{Mit}\alpha_O}{\alpha_M} \left(\ln C\left(O_{it}; w_t\right) - k_{it}\right) - s_{Mit} \left(m_{it} - k_{it}\right) &= s_{Mit} \frac{\gamma}{\alpha_M} k_{it} + s_{Mit} \frac{\phi_a}{\alpha_M}\ \tilde{a}_{it-1} \\ &\quad + s_{Mit} \frac{\phi_L}{\alpha_M} \Delta L_{it} + \frac{s_{Mit}}{\alpha_M} \tilde{\nu}_{ait} + \frac{s_{Mit}}{\alpha_M} \lambda_{it}. \end{aligned}$$

Now divide both sides by s_{Mit}

$$\frac{r_{it} - \frac{s_{Mit}\alpha_O}{\alpha_M} \left(\ln C\left(O_{it}; w_t\right) - k_{it}\right) - s_{Mit} \left(m_{it} - k_{it}\right)}{s_{Mit}} = \frac{\gamma}{\alpha_M} k_{it} + \frac{\phi_a}{\alpha_M}\ \tilde{a}_{it-1} + \frac{\phi_L}{\alpha_M} \Delta L_{it} + \frac{1}{\alpha_M} \tilde{\nu}_{ait} + \frac{1}{\alpha_M} \lambda_{it},$$

and use that $\frac{s_{Mit}\alpha_O}{\alpha_M} = s_{Oit}$

$$\frac{r_{it} - s_{Oit} \left(\ln C\left(O_{it}; w_t\right) - k_{it}\right) - s_{Mit} \left(m_{it} - k_{it}\right)}{s_{Mit}} = \frac{\gamma}{\alpha_M} k_{it} + \frac{\phi_a}{\alpha_M}\ \tilde{a}_{it-1} + \frac{\phi_L}{\alpha_M} \Delta L_{it} + \frac{1}{\alpha_M} \tilde{\nu}_{ait} + \frac{1}{\alpha_M} \lambda_{it}.$$

Define LHS_{it} as

$$LHS_{it} \equiv \frac{r_{it} - s_{Oit} \left(\ln C\left(O_{it}; w_t\right) - k_{it}\right) - s_{Mit} \left(m_{it} - k_{it}\right)}{s_{Mit}},$$

then

$$LHS_{it} \equiv \frac{\gamma}{\alpha_M} k_{it} + \frac{\phi_a}{\alpha_M} \tilde{a}_{it-1} + \frac{1}{\alpha_M} \lambda_{it} + \frac{\phi_L}{\alpha_M} \Delta L_{it} + \frac{1}{\alpha_M} \tilde{\nu}_{ait}. \tag{C-2}$$

We now solve for $\tilde{a}_{it-1}$ and λ_{it} as functions of observables. For this, we need to find expressions for $\tilde{a}_{it-2}$ and λ_{it-1}. From (8) note that

$$\lambda_{it-1} = \mu_{it-1} r_{it-1} - q_{it-1}, \tag{C-3}$$

then using this expression into (11) we obtain

$$\lambda_{it} = \phi_\lambda \left(\mu_{it-1} r_{it-1} - q_{it-1}\right) + \tilde{\nu}_{\lambda it}. \tag{C-4}$$

where $\tilde{\nu}_{\lambda it} = \delta_t^\lambda + \nu_{\lambda it}$. Now from $(C-2)$ we can obtain

$$\tilde{a}_{it-2} = \frac{\alpha_M}{\phi_a} LHS_{it-1} - \frac{\gamma}{\phi_a} k_{it-1} - \frac{1}{\phi_a}\lambda_{it-1} - \frac{\phi_L}{\phi_a}\Delta L_{it-1} - \frac{1}{\phi_a}\tilde{\nu}_{ait-1},$$

while using $(C-3)$ we get

$$\tilde{a}_{it-2} = \frac{\alpha_M}{\phi_a} LHS_{it-1} - \frac{\gamma}{\phi_a} k_{it-1} - \frac{1}{\phi_a}\left(\mu_{it-1} r_{it-1} - q_{it-1}\right) - \frac{\phi_L}{\phi_a}\Delta L_{it-1} - \frac{1}{\phi_a}\tilde{\nu}_{ait-1},$$

and after substituting this expression in (10)

$$\begin{aligned} \tilde{a}_{it-1} &= \phi_a\ \tilde{a}_{it-2} + \phi_L \Delta L_{it-1} + \tilde{\nu}_{ait-1} \\ &= \alpha_M LHS_{it-1} - \gamma k_{it-1} - 1\left(\mu_{it-1} r_{it-1} - q_{it-1}\right) - \phi_L \Delta L_{it-1} - \tilde{\nu}_{ait-1} \\ &\quad + \phi_L \Delta L_{it-1} + \tilde{\nu}_{ait-1}, \end{aligned}$$

$$\tilde{a}_{it-1} = \alpha_M LHS_{it-1} - \gamma k_{it-1} - \left(\mu_{it-1} r_{it-1} - q_{it-1}\right). \tag{C-5}$$

Using $(C-5)$ and $(C-4)$ into $(C-2)$ we obtain

$$\begin{aligned} LHS_{it} \equiv\ & \frac{\gamma}{\alpha_M} k_{it} + \phi_a LHS_{it-1} - \frac{\phi_a}{\alpha_M}\gamma k_{it-1} + \left(\frac{\phi_\lambda}{\alpha_M} - \frac{\phi_a}{\alpha_M}\right)\left(\mu_{it-1} r_{it-1} - q_{it-1}\right) \\ & + \frac{\phi_L}{\alpha_M}\Delta L_{it} + \frac{1}{\alpha_M}\left(\tilde{\nu}_{\lambda it} + \tilde{\nu}_{ait}\right), \end{aligned}$$

and using $\mu_{it} = \frac{\alpha_M}{s_{Mit}}$ we get

$$\begin{aligned} LHS_{it} =\ & \frac{1}{\alpha_M}\left(\delta_t + \delta_t^\lambda\right) + \frac{\gamma}{\alpha_M} k_{it} + \phi_a LHS_{it-1} - \gamma\frac{\phi_a}{\alpha_M} k_{it-1} + \left(\phi_\lambda - \phi_a\right)\frac{r_{it-1}}{s_{Mit-1}} \\ & + \left(\phi_a - \phi_\lambda\right)\frac{1}{\alpha_M} q_{it-1} + \frac{\phi_L}{\alpha_M}\Delta L_{it} + \frac{1}{\alpha_M}\left(\nu_{ait} + \nu_{\lambda it}\right). \end{aligned}$$

2nd stage ESTIMATION Using $\hat{b}_1$ and $\hat{b}_2$ we can implement a second stage to separately identify γ where we use the productivity process and the production function (quantity equation). Start with output

$$q_{it} = \tilde{a}_{it} + \alpha_O \ln C\left(O_{it}; w_t\right) + \alpha_M m_{it} + (\gamma - \alpha_M - \alpha_O) k_{it}.$$

From (10) and $(C-1)$ we get

$$\begin{aligned}\tilde{a}_{it} &= \phi_a \tilde{a}_{it-1} + \phi_L \Delta L_{it} + \tilde{\nu}_{ait}, \\ \tilde{a}_{it-1} &= \alpha_M LHS_{it-1} - \gamma k_{it-1} - \left(\mu_{it-1} r_{it-1} - q_{it-1}\right),\end{aligned}$$

while combining them

$$\tilde{a}_{it} = \phi_a \alpha_M LHS_{it-1} - \phi_a \gamma k_{it-1} - \phi_a \left(\mu_{it-1} r_{it-1} - q_{it-1}\right) + \phi_L \Delta L_{it} + \tilde{\nu}_{ait}.$$

We then have that log output is given by

$$\begin{aligned}q_{it} &= \alpha_O \left(\ln C\left(O_{it}; w_t\right) - k_{it}\right) + \alpha_M \left(m_{it} - k_{it}\right) + \gamma k_{it} \\ &\quad + \phi_a \alpha_M LHS_{it-1} - \phi_a \gamma k_{it-1} - \phi_a \frac{\alpha_M}{s_{Mit-1}} r_{it-1} + \phi_a q_{it-1} + \phi_L \Delta L_{it} + \tilde{\nu}_{ait}.\end{aligned}$$

where we use $\mu_{it-1} = \frac{\alpha_M}{s_{Mit-1}}$. Using (9) and parameters from the first stage

$$\begin{aligned}\alpha_O &= \gamma \frac{1}{\hat{b}_1} \frac{s_{Oit}}{s_{Mit}} \\ \alpha_M &= \gamma \frac{1}{\hat{b}_1} \\ \phi_a \alpha_M &= \gamma \frac{\hat{b}_2}{\hat{b}_1} \\ -\phi_a \gamma &= -\gamma \hat{b}_2 \\ -\phi_a \frac{\alpha_M}{s_{Mit-1}} &= -\gamma \frac{\hat{b}_2}{\hat{b}_1} \frac{1}{s_{Mit-1}} \\ \phi_a &= \hat{b}_2\end{aligned}$$

we obtain

$$\begin{aligned}q_{it} &= \gamma \frac{1}{\hat{b}_1} \frac{s_{Oit}}{s_{Mit}} \left(\ln C\left(O_{it}; w_t\right) - k_{it}\right) + \gamma \frac{1}{\hat{b}_1} \left(m_{it} - k_{it}\right) + \gamma k_{it} \\ &\quad + \gamma \frac{\hat{b}_2}{\hat{b}_1} LHS_{it-1} - \gamma \hat{b}_2 k_{it-1} - \gamma \frac{1}{\hat{b}_1} \frac{\hat{b}_2}{s_{Mit-1}} r_{it-1} + \hat{b}_2 q_{it-1} + \phi_L \Delta L_{it} + \tilde{\nu}_{ait}\end{aligned}$$

Note that the only parameters to estimate are γ and ϕ_L and in particular we only need γ to get quantity productivity, markups, etc. The two parameters are estimated using a linear model

$$q_{it} - \hat{b}_2 q_{it-1} = \delta_t + b_7 Z_{it} + b_8 \Delta L_{it} + \nu_{ait}, \tag{C-6}$$

where

$$Z_{it} = \frac{1}{\hat{b}_1} \frac{s_{Oit}}{s_{Mit}} \left(\ln C\left(O_{it}; w_t\right) - k_{it}\right) + \frac{1}{\hat{b}_1} \left(m_{it} - k_{it}\right) + k_{it} + \frac{\hat{b}_2}{\hat{b}_1} LHS_{it-1} - \hat{b}_2 k_{it-1} - \frac{1}{\hat{b}_1} \frac{\hat{b}_2}{s_{Mit-1}} r_{it-1}.$$

C.2 Time evolution of revenue TFP

Recall that

$$\bar{a}_{it} = p_{it} + \tilde{a}_{it}.$$

From (10) adding and subtracting from both sides p_{it} we obtain

$$\bar{a}_{it} = \phi_a \bar{a}_{it-1} + \phi_L \Delta L_{it} + p_{it} - \phi_a p_{it-1} + \tilde{\nu}_{ait}$$

where we also define $\tilde{\nu}_{ait} \equiv \delta_t + \nu_{ait}$. Now substitute for $p_{it} = mc_{it} + \ln(\mu_{it})$. With our production function, marginal cost is given by

$$MC_{it} = \frac{\partial C_{it}}{\partial Q_{it}} = \frac{1}{\tilde{A}_{it}^{\frac{1}{(\alpha_O+\alpha_M)}} K_{it}^{\frac{\gamma-\alpha_M-\alpha_O}{(\alpha_O+\alpha_M)}} B} 1^{\frac{\alpha_O}{(\alpha_O+\alpha_M)}} W_{Mt}^{\frac{\alpha_M}{(\alpha_O+\alpha_M)}} Q_{it}^{\frac{1-(\alpha_O+\alpha_M)}{(\alpha_O+\alpha_M)}}. \tag{C-7}$$

Besides constants and variables that will be controlled for by time dummies this can be written in log-linear form as follows

$$mc_{it} = -\frac{1}{(\alpha_O+\alpha_M)}\tilde{a}_{it} - \frac{\gamma-\alpha_M-\alpha_O}{(\alpha_O+\alpha_M)}k_{it} + \frac{1-(\alpha_O+\alpha_M)}{(\alpha_O+\alpha_M)}q_{it}, \tag{C-8}$$

using this we get

$$\bar{a}_{it} = \phi_a \bar{a}_{it-1} + \phi_L \Delta L_{it} - \frac{1}{(\alpha_O+\alpha_M)}\tilde{a}_{it} - \frac{\gamma-\alpha_M-\alpha_O}{(\alpha_O+\alpha_M)}k_{it} + \frac{1-(\alpha_O+\alpha_M)}{(\alpha_O+\alpha_M)}q_{it} + \ln(\mu_{it}) - \phi_a p_{it-1} + \tilde{\nu}_{ait}$$

Note that $q_{it} = -\eta_{it} p_{it} + (\eta_{it}-1)\lambda_{it}$, then

$$q_{it} = -\eta_{it} mc_{it} - \eta_{it}\ln(\mu_{it}) + (\eta_{it}-1)\lambda_{it},$$

then using again $(C-8)$

$$\begin{aligned} q_{it} \quad &= \quad \frac{\eta_{it}}{(\eta_{it}+(1-\eta_{it})(\alpha_O+\alpha_M))}\tilde{a}_{it} + \frac{\eta_{it}\frac{\gamma-\alpha_M-\alpha_O}{(\alpha_O+\alpha_M)}}{\left(1+\eta_{it}\frac{1-(\alpha_O+\alpha_M)}{(\alpha_O+\alpha_M)}\right)}k_{it} \\ &\quad - \frac{\eta_{it}}{\left(1+\eta_{it}\frac{1-(\alpha_O+\alpha_M)}{(\alpha_O+\alpha_M)}\right)}\ln(\mu_{it}) + \frac{(\eta_{it}-1)}{\left(1+\eta_{it}\frac{1-(\alpha_O+\alpha_M)}{(\alpha_O+\alpha_M)}\right)}\lambda_{it}. \end{aligned}$$

Substituting this expression into $\bar{a}_{it}$, we obtain

$$
\begin{aligned}
\bar{a}_{it} &= \phi_a \bar{a}_{it-1} + \phi_L \Delta L_{it} \\
&- \frac{1}{(\eta_{it} + (1-\eta_{it})(\alpha_O + \alpha_M))} \left(\phi_a \tilde{a}_{it-1} + \phi_L \Delta L_{it} + \tilde{\nu}_{ait}\right) \\
&- \frac{\gamma - \alpha_M - \alpha_O}{(\alpha_O + \alpha_M)} k_{it} + \frac{1-(\alpha_O+\alpha_M)}{(\alpha_O+\alpha_M)} \frac{\eta_{it} \frac{\gamma - \alpha_M - \alpha_O}{(\alpha_O+\alpha_M)}}{\left(1 + \eta_{it} \frac{1-(\alpha_O+\alpha_M)}{(\alpha_O+\alpha_M)}\right)} k_{it} \\
&- \frac{1-(\alpha_O+\alpha_M)}{(\alpha_O+\alpha_M)} \frac{\eta_{it}}{\left(1 + \eta_{it} \frac{1-(\alpha_O+\alpha_M)}{(\alpha_O+\alpha_M)}\right)} \ln(\mu_{it}) \\
&+ \frac{1-(\alpha_O+\alpha_M)}{(\alpha_O+\alpha_M)} \frac{(\eta_{it}-1)}{\left(1 + \eta_{it} \frac{1-(\alpha_O+\alpha_M)}{(\alpha_O+\alpha_M)}\right)} \left(\phi_\lambda \lambda_{it-1} + \tilde{\nu}_{\lambda it}\right) \\
&+ \ln(\mu_{it}) - \phi_a p_{it-1} + \tilde{\nu}_{ait},
\end{aligned}
$$

where $\tilde{\nu}_{\lambda it} = \delta_t^\lambda + \nu_{\lambda it}$. Considering that $\tilde{a}_{it-1} = \bar{a}_{it-1} - p_{it-1}$ while simplifying and regrouping terms we finally obtain

$$
\begin{aligned}
\bar{a}_{it} &= \left(1 - \frac{1}{(\eta_{it} + (1-\eta_{it})(\alpha_O + \alpha_M))}\right) \delta_t + \frac{1-(\alpha_O+\alpha_M)}{(\alpha_O+\alpha_M)} \frac{(\eta_{it}-1)}{\left(1 + \eta_{it} \frac{1-(\alpha_O+\alpha_M)}{(\alpha_O+\alpha_M)}\right)} \delta_t^\lambda \qquad \text{(C-9)} \\
&+\phi_a \left(1 - \frac{1}{(\eta_{it} + (1-\eta_{it})(\alpha_O + \alpha_M))}\right) \bar{a}_{it-1} \\
&+\phi_L \left(1 - \frac{1}{(\eta_{it} + (1-\eta_{it})(\alpha_O + \alpha_M))}\right) \Delta L_{it} \\
&+\frac{1-(\alpha_O+\alpha_M)}{(\alpha_O+\alpha_M)} \frac{(\eta_{it}-1)}{\left(1 + \eta_{it} \frac{1-(\alpha_O+\alpha_M)}{(\alpha_O+\alpha_M)}\right)} \phi_\lambda \lambda_{it-1} \\
&-\phi_a \left(1 - \frac{1}{(\eta_{it} + (1-\eta_{it})(\alpha_O + \alpha_M))}\right) p_{it-1} \\
&\left(1 - \frac{1-(\alpha_O+\alpha_M)}{(\alpha_O+\alpha_M)} \frac{\eta_{it}}{\left(1 + \eta_{it} \frac{1-(\alpha_O+\alpha_M)}{(\alpha_O+\alpha_M)}\right)}\right) \ln(\mu_{it}) \\
&+\left(\frac{1-(\alpha_O+\alpha_M)}{(\alpha_O+\alpha_M)} \frac{\eta_{it} \frac{\gamma - \alpha_M - \alpha_O}{(\alpha_O+\alpha_M)}}{\left(1 + \eta_{it} \frac{1-(\alpha_O+\alpha_M)}{(\alpha_O+\alpha_M)}\right)} - \frac{\gamma - \alpha_M - \alpha_O}{(\alpha_O+\alpha_M)}\right) k_{it} \\
&+\left(1 - \frac{1}{(\eta_{it} + (1-\eta_{it})(\alpha_O + \alpha_M))}\right) \nu_{ait} + \frac{1-(\alpha_O+\alpha_M)}{(\alpha_O+\alpha_M)} \frac{(\eta_{it}-1)}{\left(1 + \eta_{it} \frac{1-(\alpha_O+\alpha_M)}{(\alpha_O+\alpha_M)}\right)} \nu_{\lambda it}.
\end{aligned}
$$

D Production Function Estimations by Industry

Table D-1: Production function estimations by industry

		Final estimates			**1st stage coeffs**									**2nd stage coeffs**	
Industry		α_M	α_O	γ	b_1	b_2	b_3	b_4	b_5	b_6	γ 1st	ϕ_L 1st	α_M 1st	b_7	b_8
1	coeff	1.986	0.243	1.054	0.531	0.984	-0.405	-0.100	-0.089	-0.084	-0.598	0.095	-1.127	1.054	-0.060
	st dev	0.657	0.080	0.307	0.181	0.170	0.239	0.183	0.194	0.219	4.875	3.249	10.561	0.307	0.065
	t-ratio	3.024	3.024	3.438	2.935	5.787	-1.694	-0.546	-0.456	-0.386	-0.123	0.029	-0.107	3.438	-0.929
2	coeff	0.954	0.112	1.027	1.077	1.836	-0.627	-1.277	0.135	1.383	10.148	13.037	9.424	1.027	-0.724
	st dev	0.742	0.087	0.522	0.493	0.310	0.571	0.334	0.353	0.954	58.118	103.558	52.661	0.522	0.423
	t-ratio	1.285	1.285	1.967	2.184	5.920	-1.097	-3.824	0.384	1.450	0.175	0.126	0.179	1.967	-1.712
3	coeff	2.250	0.326	0.986	0.438	-1.161	1.424	1.907	-0.795	5.874	1.052	14.098	2.400	0.986	3.865
	st dev	2.017	0.292	0.859	0.946	1.431	1.506	1.535	1.192	3.990	16.566	108.487	16.222	0.859	2.641
	t-ratio	1.116	1.116	1.148	0.463	-0.811	0.946	1.243	-0.667	1.472	0.063	0.130	0.148	1.148	1.463
4	coeff	0.704	0.127	0.990	1.406	1.103	-0.986	-0.378	-0.181	0.301	-2.933	-0.627	-2.086	0.990	0.058
	st dev	0.121	0.022	0.156	0.116	0.150	0.214	0.166	0.183	0.434	28.387	4.408	21.226	0.156	0.145
	t-ratio	5.814	5.814	6.350	12.074	7.339	-4.600	-2.271	-0.992	0.693	-0.103	-0.142	-0.098	6.350	0.398
5	coeff	0.713	0.163	0.991	1.390	0.951	-1.029	-0.127	-0.165	-0.827	-1.069	0.636	-0.769	0.991	0.112
	st dev	0.144	0.033	0.175	0.155	0.132	0.237	0.144	0.158	0.547	62.502	29.813	46.113	0.175	0.183
	t-ratio	4.933	4.933	5.675	8.987	7.186	-4.333	-0.881	-1.040	-1.513	-0.017	0.021	-0.017	5.675	0.616
6	coeff	0.649	0.173	1.038	1.598	1.110	-1.329	-0.272	-0.119	0.049	-3.649	-0.113	-2.284	1.038	-0.053
	st dev	0.189	0.050	0.240	0.241	0.197	0.321	0.217	0.218	0.649	33.287	7.531	20.052	0.240	0.113
	t-ratio	3.445	3.445	4.321	6.621	5.638	-4.144	-1.257	-0.547	0.076	-0.110	-0.015	-0.114	4.321	-0.469
7	coeff	1.105	0.270	1.177	1.065	1.145	-0.736	-0.304	-0.103	1.856	-3.134	-5.460	-2.943	1.177	-0.128
	st dev	0.762	0.186	0.540	0.813	0.295	0.826	0.342	0.219	1.416	22.134	56.903	18.599	0.540	0.465
	t-ratio	1.451	1.451	2.181	1.309	3.873	-0.891	-0.889	-0.472	1.311	-0.142	-0.096	-0.158	2.181	-0.275
8	coeff	0.546	0.101	0.860	1.577	0.659	-0.788	0.059	-0.468	0.541	0.198	0.068	0.126	0.860	-0.017
	st dev	0.135	0.025	0.179	0.199	0.300	0.379	0.303	0.327	0.817	14.357	10.458	11.574	0.179	0.472
	t-ratio	4.054	4.054	4.799	7.932	2.198	-2.081	0.194	-1.430	0.662	0.014	0.007	0.011	4.799	-0.035
9	coeff	1.234	0.303	1.064	0.862	1.189	-0.492	-0.432	-0.261	-0.114	-1.428	0.189	-1.655	1.064	-0.031
	st dev	0.490	0.120	0.288	0.211	0.134	0.260	0.147	0.156	0.224	125.055	33.314	141.990	0.288	0.054
	t-ratio	2.515	2.515	3.698	4.080	8.857	-1.892	-2.946	-1.669	-0.510	-0.011	0.006	-0.012	3.698	-0.570
10	coeff	0.252	0.060	0.719	2.849	0.967	-1.740	-0.311	-0.407	1.095	-2.175	-0.836	-0.763	0.719	1.870
	st dev	0.146	0.035	0.280	0.905	0.847	0.854	1.069	0.694	3.838	33.919	37.182	10.094	0.280	1.627
	t-ratio	1.723	1.723	2.565	3.150	1.141	-2.037	-0.291	-0.587	0.285	-0.064	-0.022	-0.076	2.565	1.150
11	coeff	0.996	0.116	0.887	0.890	0.546	0.150	-0.330	-0.067	0.060	-4.358	-0.295	-4.897	0.887	-0.023
	st dev	0.389	0.045	0.209	0.289	0.512	0.557	0.621	0.456	0.449	39.547	43.679	41.260	0.209	0.182
	t-ratio	2.559	2.559	4.252	3.075	1.067	0.269	-0.531	-0.148	0.134	-0.110	-0.007	-0.119	4.252	-0.123
12	coeff	0.215	0.024	0.711	3.303	0.956	-2.568	-0.596	-0.053	-0.981	-37.036	11.000	-11.213	0.711	0.052
	st dev	0.098	0.011	0.236	1.051	0.605	1.145	0.642	0.639	0.392	20.127	6.953	6.297	0.236	0.063
	t-ratio	2.198	2.198	3.015	3.144	1.581	-2.243	-0.929	-0.083	-2.504	-1.840	1.582	-1.781	3.015	0.817
13	coeff	0.442	0.117	0.789	1.783	1.113	-1.460	-0.278	-0.052	1.302	-9.488	-6.927	-5.320	0.789	0.089
	st dev	0.347	0.092	0.444	0.858	0.267	0.960	0.298	0.433	0.845	13.540	11.084	7.419	0.444	0.138
	t-ratio	1.275	1.275	1.778	2.079	4.165	-1.521	-0.933	-0.121	1.541	-0.701	-0.625	-0.717	1.778	0.643
14	coeff	0.476	0.100	0.877	1.842	1.163	-1.360	-0.437	-0.337	-0.174	-2.386	0.226	-1.295	0.877	-0.008
	st dev	0.301	0.063	0.403	0.458	0.184	0.514	0.199	0.208	0.283	12.227	1.559	6.706	0.403	0.039
	t-ratio	1.582	1.582	2.175	4.022	6.316	-2.644	-2.191	-1.624	-0.616	-0.195	0.145	-0.193	2.175	-0.219
15	coeff	0.760	0.113	0.903	1.188	1.094	-0.869	-0.349	-0.070	0.480	-5.905	-2.384	-4.969	0.903	0.044
	st dev	0.242	0.036	0.237	0.206	0.127	0.237	0.143	0.141	0.275	16.740	8.888	13.727	0.237	0.071
	t-ratio	3.144	3.144	3.814	5.779	8.615	-3.660	-2.452	-0.498	1.743	-0.353	-0.268	-0.362	3.814	0.610
16	coeff	0.621	0.086	0.884	1.423	0.913	-0.781	-0.238	-0.376	0.306	-0.902	-0.194	-0.634	0.884	0.072
	st dev	0.211	0.029	0.273	0.191	0.307	0.361	0.333	0.330	0.284	24.059	8.461	17.499	0.273	0.109
	t-ratio	2.945	2.945	3.238	7.437	2.977	-2.163	-0.716	-1.139	1.080	-0.037	-0.023	-0.036	3.238	0.660
17	coeff	0.547	0.100	0.991	1.813	1.518	-1.594	-0.723	-0.095	1.589	-13.763	-12.064	-7.594	0.991	0.001
	st dev	0.385	0.070	0.614	0.379	0.383	0.515	0.427	0.315	0.732	39.834	42.998	22.489	0.614	0.296
	t-ratio	1.419	1.419	1.613	4.779	3.961	-3.095	-1.692	-0.303	2.169	-0.346	-0.281	-0.338	1.613	0.004
18	coeff	0.464	0.109	0.911	1.965	0.959	-1.832	-0.113	-0.007	0.381	-31.362	-6.077	-15.963	0.911	0.058
	st dev	0.148	0.035	0.254	0.321	0.264	0.416	0.289	0.208	0.510	24.258	11.958	13.634	0.254	0.131
	t-ratio	3.138	3.138	3.581	6.112	3.636	-4.403	-0.389	-0.034	0.746	-1.293	-0.508	-1.171	3.581	0.440
19	coeff	0.532	0.106	0.976	1.837	1.370	-1.907	-0.561	0.134	0.315	7.703	1.322	4.193	0.976	-0.005
	st dev	0.342	0.068	0.420	0.325	0.257	0.440	0.278	0.289	0.432	123.895	13.284	68.576	0.420	0.086
	t-ratio	1.555	1.555	2.327	5.645	5.327	-4.331	-2.017	0.463	0.730	0.062	0.099	0.061	2.327	-0.055
20	coeff	0.382	0.136	0.755	1.979	0.922	-1.244	0.011	-0.663	-0.737	0.034	-0.013	0.017	0.755	0.055
	st dev	0.165	0.059	0.262	0.785	0.313	0.747	0.350	0.311	0.852	1.955	0.992	1.163	0.262	0.124
	t-ratio	2.320	2.320	2.882	2.522	2.947	-1.667	0.033	-2.128	-0.864	0.017	-0.013	0.015	2.882	0.441
21	coeff	0.732	0.136	0.842	1.149	0.923	-0.866	-0.134	0.023	-1.170	6.672	-6.792	5.805	0.842	-0.114
	st dev	0.611	0.113	0.575	0.634	0.257	0.658	0.274	0.299	0.511	9.204	9.640	8.129	0.575	0.087
	t-ratio	1.198	1.198	1.463	1.812	3.594	-1.316	-0.488	0.077	-2.290	0.725	-0.705	0.714	1.463	-1.303

Notes: Bootstrapped standard errors.

Continuation of Table D-1

		Final estimates			**1st stage coeffs**									**2nd stage coeffs**	
Industry		α_M	α_O	γ	b_1	b_2	b_3	b_4	b_5	b_6	γ 1st	ϕ_L 1st	α_M 1st	b_7	b_8
22	coeff	0.697	0.089	0.982	1.409	0.831	-1.053	0.023	-0.199	-0.640	0.162	-0.073	0.115	0.982	-0.058
	st dev	0.190	0.024	0.235	0.180	0.176	0.267	0.185	0.195	0.387	1547.564	842.053	1130.622	0.235	0.077
	t-ratio	3.663	3.663	4.178	7.822	4.714	-3.940	0.123	-1.020	-1.652	0.000	0.000	0.000	4.178	-0.744
23	coeff	0.376	0.044	0.883	2.347	0.831	-2.186	0.086	-0.097	0.652	2.074	0.576	0.883	0.883	-0.431
	st dev	0.218	0.025	0.375	0.553	0.225	0.571	0.249	0.125	0.473	21.844	4.939	10.910	0.375	0.176
	t-ratio	1.726	1.726	2.356	4.244	3.702	-3.828	0.345	-0.780	1.378	0.095	0.117	0.081	2.356	-2.455
24	coeff	0.799	0.170	1.009	1.263	0.821	-0.962	0.083	-0.251	-0.245	0.418	-0.081	0.331	1.009	0.070
	st dev	0.326	0.069	0.325	0.258	0.155	0.288	0.169	0.165	0.415	12.158	2.496	9.002	0.325	0.114
	t-ratio	2.450	2.450	3.104	4.901	5.299	-3.344	0.491	-1.518	-0.590	0.034	-0.032	0.037	3.104	0.608
25	coeff	0.606	0.142	0.727	1.199	1.126	-1.107	-0.200	-0.065	1.537	-3.668	-4.702	-3.059	0.727	0.031
	st dev	0.596	0.140	0.304	0.490	0.334	0.461	0.353	0.174	0.922	56.557	132.674	60.124	0.304	0.294
	t-ratio	1.017	1.017	2.387	2.447	3.372	-2.401	-0.566	-0.377	1.668	-0.065	-0.035	-0.051	2.387	0.107
26	coeff	0.758	0.215	0.965	1.273	1.135	-1.003	-0.314	0.028	-0.279	14.534	-3.180	11.419	0.965	0.081
	st dev	0.397	0.112	0.358	0.386	0.147	0.381	0.161	0.160	0.336	21.490	5.399	16.715	0.358	0.046
	t-ratio	1.908	1.908	2.691	3.293	7.723	-2.633	-1.956	0.172	-0.830	0.676	-0.589	0.683	2.691	1.742
27	coeff	0.506	0.142	0.979	1.937	1.438	-1.237	-0.749	-0.065	-0.164	-22.195	1.883	-11.461	0.979	-0.021
	st dev	0.276	0.078	0.476	0.448	0.573	0.793	0.634	0.760	0.839	77.641	28.354	46.658	0.476	0.403
	t-ratio	1.835	1.835	2.056	4.327	2.510	-1.560	-1.182	-0.086	-0.196	-0.286	0.066	-0.246	2.056	-0.052
28	coeff	1.025	0.228	1.105	1.078	1.382	-1.043	-0.605	0.107	0.688	6.118	3.903	5.675	1.105	0.206
	st dev	1.393	0.310	0.981	0.944	0.409	1.004	0.438	0.409	0.532	73.680	33.076	36.875	0.981	0.188
	t-ratio	0.736	0.736	1.127	1.143	3.383	-1.039	-1.381	0.260	1.293	0.083	0.118	0.154	1.127	1.096
29	coeff	0.634	0.218	1.034	1.630	0.880	-0.461	-0.151	-0.695	0.621	-0.355	-0.135	-0.218	1.034	0.111
	st dev	0.384	0.132	0.466	0.738	0.410	0.965	0.449	0.684	0.859	8.694	5.110	5.253	0.466	0.089
	t-ratio	1.650	1.650	2.221	2.210	2.146	-0.478	-0.337	-1.015	0.723	-0.041	-0.026	-0.041	2.221	1.257
30	coeff	0.708	0.186	0.982	1.386	1.427	-1.527	-0.543	0.078	0.295	9.705	2.066	7.003	0.982	-0.230
	st dev	0.441	0.116	0.482	0.451	0.255	0.552	0.281	0.313	0.810	28.269	47.277	23.158	0.482	0.398
	t-ratio	1.606	1.606	2.035	3.072	5.606	-2.766	-1.932	0.247	0.364	0.343	0.044	0.302	2.035	-0.579
31	coeff	0.725	0.226	1.024	1.412	1.272	-1.225	-0.477	-0.073	-0.043	-9.209	0.278	-6.522	1.024	-0.027
	st dev	0.299	0.093	0.323	0.281	0.164	0.327	0.181	0.170	0.484	114.616	21.381	74.139	0.323	0.167
	t-ratio	2.423	2.423	3.167	5.026	7.779	-3.742	-2.628	-0.431	-0.088	-0.080	0.013	-0.088	3.167	-0.163
32	coeff	0.607	0.163	0.990	1.629	1.199	-1.424	-0.455	0.040	0.547	18.627	6.251	11.434	0.990	-0.071
	st dev	0.365	0.098	0.328	0.421	0.175	0.455	0.192	0.177	0.496	60.765	13.372	26.222	0.328	0.102
	t-ratio	1.666	1.666	3.019	3.867	6.861	-3.128	-2.372	0.225	1.103	0.307	0.467	0.436	3.019	-0.695
33	coeff	0.464	0.146	1.041	2.243	1.116	-2.019	-0.278	-0.098	-1.639	-6.330	4.625	-2.822	1.041	0.372
	st dev	0.217	0.068	0.429	0.709	0.367	0.788	0.406	0.373	1.185	16.062	15.211	6.010	0.429	0.257
	t-ratio	2.137	2.137	2.429	3.164	3.044	-2.562	-0.683	-0.264	-1.383	-0.394	0.304	-0.470	2.429	1.447
34	coeff	0.434	0.145	0.974	2.242	2.127	-2.200	-1.533	0.161	1.940	21.342	18.462	9.518	0.974	-0.193
	st dev	0.139	0.046	0.187	0.472	0.194	0.496	0.218	0.148	0.716	333.452	318.260	141.900	0.187	0.257
	t-ratio	3.114	3.114	5.214	4.746	10.946	-4.436	-7.022	1.085	2.708	0.064	0.058	0.067	5.214	-0.749
35	coeff	0.561	0.081	0.876	1.561	1.052	-1.698	-0.139	0.163	-1.239	1.332	-1.057	0.853	0.876	-0.035
	st dev	0.200	0.029	0.280	0.284	0.295	0.413	0.283	0.242	0.690	130.386	12.485	83.059	0.280	0.268
	t-ratio	2.809	2.809	3.130	5.500	3.564	-4.112	-0.490	0.671	-1.797	0.010	-0.085	0.010	3.130	-0.130
36	coeff	0.841	0.185	1.126	1.340	1.136	-1.160	-0.310	-0.122	-0.503	-3.414	1.282	-2.548	1.126	0.115
	st dev	0.718	0.158	0.543	0.580	0.174	0.592	0.183	0.128	0.617	57.560	72.913	30.864	0.543	0.202
	t-ratio	1.171	1.171	2.074	2.308	6.530	-1.958	-1.692	-0.947	-0.815	-0.059	0.018	-0.083	2.074	0.569
37	coeff	0.779	0.118	1.393	1.788	0.914	-0.954	-0.124	-0.758	-1.527	-0.293	0.251	-0.164	1.393	0.066
	st dev	0.462	0.070	0.628	0.943	0.450	1.174	0.502	0.594	1.520	11.416	7.777	4.683	0.628	0.526
	t-ratio	1.688	1.688	2.218	1.896	2.033	-0.812	-0.248	-1.276	-1.005	-0.026	0.032	-0.035	2.218	0.125
38	coeff	0.348	0.068	0.790	2.266	2.801	-2.973	-2.416	1.550	3.674	3.534	5.730	1.559	0.790	-0.563
	st dev	0.198	0.039	0.434	1.517	0.576	1.532	0.705	0.649	1.536	3.510	4.335	0.977	0.434	3.257
	t-ratio	1.756	1.756	1.821	1.494	4.864	-1.941	-3.426	2.388	2.392	1.007	1.322	1.595	1.821	-0.173
39	coeff	0.994	0.185	1.101	1.108	1.134	-0.932	-0.435	-0.038	-0.124	-12.538	1.402	-11.317	1.101	-0.364
	st dev	0.828	0.154	0.551	0.597	0.202	0.617	0.239	0.184	0.976	47.010	17.281	46.608	0.551	0.351
	t-ratio	1.200	1.200	1.999	1.857	5.621	-1.511	-1.817	-0.208	-0.127	-0.267	0.081	-0.243	1.999	-1.036
40	coeff	0.598	0.148	0.860	1.438	0.680	-0.620	0.032	-0.850	0.037	0.054	0.001	0.038	0.860	-0.164
	st dev	0.286	0.071	0.323	0.528	0.517	0.745	0.540	0.681	2.150	4.724	5.305	3.345	0.323	0.494
	t-ratio	2.094	2.094	2.663	2.723	1.315	-0.832	0.059	-1.249	0.017	0.011	0.000	0.011	2.663	-0.331
41	coeff	0.603	0.289	1.017	1.687	0.889	-1.620	0.059	0.258	1.426	-0.384	-0.324	-0.227	1.017	-0.020
	st dev	0.510	0.245	0.336	0.708	0.304	0.737	0.303	0.273	1.707	62.183	43.883	30.061	0.336	0.298
	t-ratio	1.182	1.182	3.023	2.385	2.928	-2.198	0.194	0.945	0.836	-0.006	-0.007	-0.008	3.023	-0.068
42	coeff	0.719	0.195	1.138	1.583	1.292	-1.545	-0.547	0.092	0.097	9.374	0.573	5.921	1.138	-0.155
	st dev	0.324	0.088	0.335	0.332	0.119	0.338	0.132	0.110	0.370	50.326	6.743	29.420	0.335	0.073
	t-ratio	2.220	2.220	3.403	4.772	10.819	-4.573	-4.144	0.838	0.262	0.186	0.085	0.201	3.403	-2.117

Notes: Bootstrapped standard errors.

E A Case Study: Firm Outcomes from the Removal of EU Quotas on Textile and Apparel

In this Appendix we focus on a specific industry, "Textile and Apparel", that experienced a rise in import competition from China during our time frame. As a consequence of China joining the WTO a number of quotas that were imposed at the EU-level on Chinese imports—as well as on imports from other non-WTO countries—were removed. These quotas used to affect some products within the "Textile and Apparel" industry but not others.

We show how the removal of quotas corresponds to a negative demand shock that forced firms to reorganize. In particular, we show that firms that decrease the number of layers experience a reduction in quantity-based productivity and an increase in revenue-based productivity. The data and estimation strategy are borrowed from Bloom, Draca, and Van Reenen (2016) to which the reader may refer for further details. To provide some context, when these quotas were abolished this generated a 240% increase in Chinese imports on average within the affected product groups. The underlying identifying assumption of this strategy is that unobserved demand/technology shocks are uncorrelated with the strength of quotas to non-WTO countries (like China) in 2000. Since these quotas were built up from the 1950s, and their phased abolition negotiated in the late 1980s was in preparation for the Uruguay Round, Bloom, Draca, and Van Reenen (2016) conclude that this seems like a plausible assumption.

Operationally we compute for each 6-digit Prodcom product category, the proportion of the more detailed 6-digit HS products that were covered by a quota, weighting each HS6 product by its share of EU15 imports over the period 1995-1997. Then, for each firm, we measure the firm-level exposure to the quota by adding each of the 6-digit Prodcom products weighted by the initial share of sales of the firm in that product. We keep this sales shares constant. We label this variable $QuotaCoverage_i$, and focus on the period 2000-2005.

Figure E-1: Average number of management layers for firms affected and not affected by the quota removals,

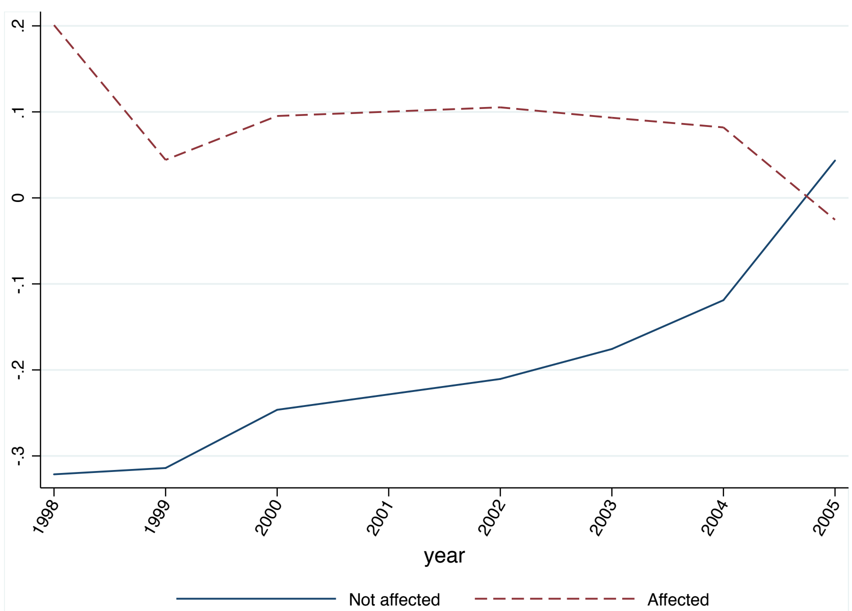

Figure E-1 shows the average number of layers for firms affected and not affected by the quota removals, as a deviation from the common year average. The number of layers tend to increase for firms that were not affected by the quota removals, while it decreases for firms that were affected by the quota removals. We use this relationship as a first stage in a 2SLS specification. Namely, we instrument the change in the number of management layers with a fourth-order polynomial in $QuotaCoverage_i$ and the lagged number of layers. For the structural quantity equation we treat the change in layers as endogeneous. In the structural revenue-TFP regressions, we also consider the log of the markup in t as an additional endogeneous variable.

Table E-1 presents the results from the first stage. The sample is comprised of firms that were affected by the changes in quotas applied to the "Textile and Apparel" industry as a consequence of China's entry into the WTO. We apply a trimming of 0.5 percent to the bottom and top of the distribution of TFPQ. As we can see, the coefficients from the first stage are significant and with the expected sign. Table 9, in the main text, reports IV estimates of the effect of the change in the number of layers on either revenue-based or quantity based productivity as well as the OLS coefficients.

Table E-1: Textile and Apparel, first stage

VARIABLES	Chg layers (QTFP)	Chg layers (RTFP)	Markups (RTFP)
$QuotaCoverage_t$ (QC)	22.799[b]	18.599[c]	0.904
	(9.34)	(9.97)	(1.78)
# of layers t-1 (L_{t-1})	15.318[b]	13.819[b]	-0.038
	(6.82)	(6.66)	(1.62)
QC$*L_{t-1}$	-26.615[b]	-24.060[b]	-1.392
	(11.77)	(11.78)	(2.35)
QC squared	-20.991	-12.151	1.384
	(12.94)	(13.96)	(3.09)
L_{t-1} squared	-8.533[b]	-7.799[b]	0.108
	(3.57)	(3.47)	(0.86)
QC squared$*L_{t-1}$	12.225[b]	10.648[c]	0.387
	(5.90)	(6.26)	(1.29)
QC$*L_{t-1}$ squared	11.419[b]	10.478[b]	0.367
	(5.02)	(4.90)	(1.06)
QC cubed	6.62	-2.583[a]	-0.615
	(11.78)	(12.75)	(3.64)
L_{t-1} cubed	1.441[b]	1.322[b]	-0.026
	(0.58)	(0.56)	(0.14)
QC to the power of four	-0.009	3.436	-1.526
	(4.69)	(5.39)	(1.77)
QC cubed$*L_{t-1}$	-2.389	-1.806	0.925
	(1.81)	(1.88)	(0.62)
QC$*L_{t-1}$ cubed	-1.714[b]	-1.580[b]	0.001
	(0.69)	(0.67)	(0.15)
QC squared$*L_{t-1}$ squared	-1.64	-1.507	-0.366[c]
	(1.10)	(1.10)	(0.22)
QTFP$_{t-1}$	0.003		
	(0.03)		
RTFP$_{t-1}$		-0.196	-0.259[a]
		(0.16)	(0.10)
Demand$_{t-1}$		0.006	0.050[a]
		(0.00)	(0.00)
Price$_{t-1}$		-0.019	-0.026
		(0.03)	(0.03)
(log) Capital first year		0.046[a]	-0.019[a]
		(0.01)	(0.01)
Observations	554	554	
Kleibergen-Paap rk stat.	42.03	32.50	

Firm-product-level clustered standard errors in parentheses. [a] $p<0.01$, [b] $p<0.05$, [c] $p<0.10$