

The optimal use of management*

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We analyze the management input from the perspective of a shadow cost minimizing firm. With the help of Bloom and Van Reenen (2007)'s management measure we estimate management's shadow price, dual Morishima elasticities of substitution, and relative price efficiencies vis-à-vis labor and capital. We find that the shadow price of management is about 1.3 million US dollars per survey scale point. Management is a weak complement for labor but a strong complement for capital. Increases in management reduce the relative income share of labor but not capital. Most firms use too little management relative to both labor and capital, but relative use of management improves over time, with the combination of ownership and control, and competition. Our results suggest that management behaves similar to other inputs.

Keywords: management; shadow price; elasticity of substitution; price efficiency
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1. Introduction

Recently, in addition to “hard” technology factors (e.g. R&D, ICT), economists started to focus on “soft” technology factors (organizational practices) to better understand empirical firm performance.¹ In their seminal contribution Bloom and Van Reenen (2007), for the first time, measured firm-level management practices across countries and firms;² greatly expanding the potential for the empirical analysis of firm performance. Bloom et al. (2019) showed that management practices explain at least as large a share of cross-plant productivity variation as R&D, ICT, or human capital. But despite the wealth of this new data and the empirical relevance of management, there has been little effort to relate it to theoretical models of firm behavior, with the exception of Bloom et al. (2016).

In this paper we explore management’s characteristics when viewed as a production input. What is its shadow price? What is its elasticity of substitution, and do firms use it efficiently relative to other inputs? We apply one of the most fundamental models of producer behavior -shadow cost minimization- to the new management data. In the model firms minimize cost subject to *shadow* instead of market prices. The shadow price of management is the price that “supports” or is consistent with observed firm behavior and is estimated from the data.³ This model is relevant for the understanding of management as it is usually defined as an intangible input (Bloom and Van Reenen, 2007; Corrado and Hulten, 2010; Bloom et al., 2016) where “management should be thought of as endogenously chosen by a firm and paid a wage commensurate with its contribution to marginal productivity” (Bloom et al., 2014, p. 33). The shadow cost minimization

¹For instance, the OECD’s 2005 Oslo Manual (OECD, 2005) for the first time recognized organizational innovation alongside product and process innovation as an important driver of firm performance.

²Traditionally, management has been measured as a residual, e.g. Farrell (1957) or Mundlak (1961). Also, there have been case studies of organizational practices in single firms (Ichniowski and Shaw, 2009). Other surveys of management practices, although with less coverage, are the Community Innovation Survey or the UK’s Workplace Employment Relations Survey (WERS).

³Mefford (1986) estimates a production function including observed management as an input. He also uses the testing procedure of Hanoch and Rothschild (1972) to show that the inclusion of the management input reduces the number of observations that violate theoretical restrictions on the production function.

model is useful for three reasons. First, it allows us to estimate the unobserved (shadow) price of management. Even though absolute input prices are not relevant for economic decision making, the shadow price is of interest because management practices like many other intangibles have no market price. Second, it allows us to estimate own as well as cross-price (partial and ratio) dual elasticities of substitution. These provide information about the technological difficulty of substitution as well as how relative input cost shares change with inputs. Third, we can analyze firm decision making in terms of whether firms use management optimally relative to its own opportunity cost (competitive market prices) and that of other inputs. As shadow cost minimization is equivalent to utility maximization (Atkinson and Halvorsen, 1986) the model also allows us to explore the mechanisms for the inefficient use of management. Firm objectives other than profit maximization, or constraints other than the technology are reflected in deviations of shadow prices from market prices. That wedge determines a firm’s price efficiency, which can be either (i) absolute, i.e. shadow prices equal actual prices or (ii) relative, i.e. for any two inputs the ratio of shadow prices equals the ratio of actual prices. Managers’ utility maximization behavior could be due to the separation of ownership and control. Also, some owners could maximize utility. For instance, Lemos and Scur (2019) argue that family-controlled firms do not adopt “best practice” management due to family-utility maximization. The model shows that price efficiency depends on how sensitive utility is to input use and profits. If, for instance, managers’ utility decreases in the management input (effort) firms will employ too little management relative to the other inputs (assuming other inputs are less sensitive to effort). We use ownership type as a proxy for how sensitive utility is to management use and we use market competitiveness as a proxy for how sensitive utility is to profit.

For our estimation we use an input distance function (IDF). This dual to the cost function facilitates the estimation of (absolute) shadow prices and only requires data on physical input and output quantities (Shephard, 1970; Färe and Grosskopf, 1990). Also, shadow prices (indirect demand) provide a natural measure for input substitutability⁴,

⁴For two inputs the technical and economic substitution possibilities are identical but for more than

the Dual Morishima Elasticity of Substitution (Blackorby and Russell, 1981), i.e. shadow price changes in response to quantity changes.

Our data for firm-level management practices, inputs, output, and prices is from Bloom and Van Reenen (2007). The management variable is based on a survey and is measured on a 5-point Likert scale. The sample comprises medium-sized manufacturing firms from the US, Germany, France, and the UK (first wave of the World Management Survey). Our ability to analyze management’s price efficiency is limited by the absence of an observed market price for abstract management practices. However, many of their ingredients do have prices; examples are (top) management salaries or consulting fees.⁵ We take CEO compensation as a proxy for the price of abstract management practices. Even though Bloom and Van Reenen (2007) stress that they do not measure managers’ ability, managers’ compensation is likely to correlate with the price (marginal product) of management practices.⁶ One reason is that individual managers influence organizational practices, and are rewarded for good firm performance (Bertrand and Schoar, 2003). Also, increasingly, managers are selected for their general management, as opposed to firm-specific, skills (Bertrand, 2009, p. I.3). These factors should imply a correlation between managers’ pay and firm’s organizational practices. Such a correlation is also consistent with “Talent as a Factor of Production” models where CEO talent determines how well the other inputs are managed (Edmans et al., 2017). Empirically, we find that the correlation coefficient between management compensation and our estimated shadow price of management is about 0.85 for the US sub-sample for which we observe both prices.

We find that the average shadow price (and value of marginal product) of management is about 1.3 million US dollars per point on the survey scale. All our results hold

two inputs analysis of economic substitution is more convenient, in particular it allows the firm to also adjust other inputs than the two input under consideration.

⁵Bloom et al. (2013) and Bruhn et al. (2018) provide experimental evidence that consulting services improve management practices and firm performance.

⁶On p. 1355 they say: “We see management practices as more than the attributes of the top managers: they are part of the organizational structure and behavior of the firm, typically evolving slowly over time even as CEOs and CFOs come and go.”

controlling for time-invariant firm heterogeneity. Viewed through the lens of shadow cost minimization behavior, management is no different from other inputs like capital or labor. As predicted, management’s own-quantity elasticity is negative. Management is a dual Morishima complement for labor (relatively weak) and capital (relatively strong) in the generation of value added. Complementarities are such that an increase in management reduces the relative income share of labor, but might increase the relative share of capital. Relative price efficiencies indicate that most firms use too little management relative to both capital and labor, but the extent of over-utilization depends on the proxy for the price of management. We find that the efficient use of management varies with time, ownership, and competition. Firms learn and improve management’s relative use with time. As predicted, management’s relative price efficiency depends on the extent of utility maximization behavior. Taking ownership type as a proxy for utility maximization, we find that founder and manager-owned firms are relatively efficient. They, as opposed to other ownership forms, are less likely to maximize utility instead of profit as they combine ownership and control. Finally, we find evidence that management’s price efficiency is higher in more competitive industries, consistent with the prediction that competition increases utility’s responsiveness to profit (Willig, 1987). For models that treat management as a technology the reason why firm do not use the optimal, i.e. maximum, amount of management is slow diffusion possibly due to informational constraints (Van Reenen, 2011). Our evidence suggests that firms do not use the maximum amount because management has a cost, too. And the reason why firms do not use the optimal amount is utility maximization, which in turn is due to a separation of ownership and control and/or lack of competition.

We contribute to the fast developing literature on the impact of formal (or structured) management practices on firm performance (Bloom and Van Reenen, 2007; Forth and Bryson, 2019; Bloom et al., 2019, and references therein). Most papers in this literature model management as a technology shifter⁷ and find that better management practices positively correlate with total factor or labor productivity. However, these papers do not

⁷Trieb and Kumbhakar (2018) discuss the modeling of management as a technology shifter.

explicitly model firm behavior or analyze firm input decisions with regard to management. One exception and closest to ours is work by Bloom et al. (2016). Whereas in our model firms minimize long-run shadow cost, in their model (“management as technology”) firms maximize profit and choose the optimal amount of management for a dynamic investment problem with adjustment costs. Our shadow price captures depreciation and opportunity costs, but not adjustment costs for management.⁸ Our results contribute to the debate about what the right conception of management is. Van Reenen (2011) contrasts the “management as input”, “management as design”, and “management as technology” views and argues that observed productivity differences provide evidence for the latter. Both the technology and input models contrast with the design model in that output monotonically increases with management. The design model implies that all management practices are highly contingent and predictions like “management increases productivity” are not possible. We also contribute to the literature on the drivers of management practices. Whereas the previous literature found that competition and ownership type (Bloom and Van Reenen, 2007; Van Reenen, 2011; Bloom et al., 2019) affect the amount of management practices we find that it also affects its optimal use relative to other inputs. Similar to Lemos and Scur (2019) we stress that utility maximization is another important driver for the choice of management practices. Our results also relate to the literature on the complementarity between advanced, in particular ICT, capital goods and organizational/management practices (Bresnahan et al., 2002; Bloom et al., 2012; Giorcelli, 2019). Although our results are not directly comparable, because we use a more aggregate measure of capital and because we identify complementarity along an iso-quant and not the output expansion path, we also find that management and capital are complements. Finally, we contribute to a broad literature that analyzes the efficient use of inputs at the firm level. Whereas most papers in this literature show that specific market characteristics, like rate-of-return regulation (Atkinson and Halvorsen, 1986) or monopsony power in factor markets (Grosskopf et al., 1990) lead to inefficient

⁸Trieb and Kumbhakar (2013) use the WMS data to estimate a model where technical change is a function of management and find that technical change does not necessarily increase in management.

relative input choices, we show that more broadly firms are inefficient in their relative use of management and could reduce their cost by adjusting their relative management input.

The structure of this paper is as follows. Section 2 introduces our theoretical model. Section 3 shows our estimation strategy. Section 4 summarizes the data. Section 5 gives the results, and section 6 concludes.

2. Model

This section first shows how the equivalence between utility maximization and shadow cost minimization can help us understand why firms deviate from (relative) price efficiency. Second, it shows how the duality between the input distance function and the shadow cost function allows us to derive shadow prices, elasticities of substitution and (relative) price efficiencies.

Cost minimizing behavior subject to shadow prices is equivalent to utility maximization behavior (Atkinson and Halvorsen, 1986) and the latter offers insights into why firms do not use inputs efficiently. The decision maker (owner or agent) has utility function $U(\pi, X)$, where π is profit and X is the input vector. The firm faces a downward sloping demand curve and the twice differentiable concave revenue function is $R(X)$. W is the vector of input prices. The constrained maximization problem is:

$$\begin{aligned} \max_{\pi, X} U(\pi, X) \\ \text{s.t. } \pi = R(X) - \sum_k w_k x_k, \end{aligned}$$

where the revenue function implicitly contains the demand constraint and utility contains the technology constraint. The problem's Lagrangian form is:

$$\mathcal{L} = U(\pi, X) - \lambda \left[\pi - R(X) + \sum_k w_k x_k \right].$$

The first order condition for input i is:

$$\frac{\partial \mathcal{L}}{\partial x_k} = \frac{\partial U}{\partial x_k} + \lambda \frac{\partial R}{\partial x_k} - \lambda w_k = 0.$$

Using the envelope result that $\lambda = \frac{\partial U}{\partial \pi}$, we obtain:

$$\frac{\partial \mathcal{L}}{\partial w_k} = \frac{\partial U}{\partial x_k} + \frac{\partial U}{\partial \pi} \frac{\partial R}{\partial x_k} - \frac{\partial U}{\partial \pi} w_k = 0,$$

and rearranging we obtain:

$$\frac{\partial R}{\partial x_k} = w_k - \frac{\frac{\partial U}{\partial x_k}}{\frac{\partial U}{\partial \pi}} = w_k^S.$$

The left term is the marginal revenue product. The middle term shows that the shadow price w_k^S equals the market price w_k minus a bias term, which captures *absolute* price inefficiency. The numerator of the bias term reveals that the larger the absolute sensitivity of utility to the amount of input i the larger the bias and the greater is absolute price inefficiency. Also, the more sensitive utility is to profit the smaller the bias and the lower is absolute price inefficiency. Atkinson and Halvorsen (1986, p. 284) stress that we cannot use this relationship to analyze the demand for a specific input as a change in the price for input k might lead to a quantity change for j and a shift in the marginal revenue product curve. But we can use *relative* price efficiency to analyze the relative use or demand for an input. Dividing the marginal revenue products for inputs k and j we obtain:

$$\frac{\frac{\partial R}{\partial x_k}}{\frac{\partial R}{\partial x_j}} = \frac{w_k - \frac{\partial U}{\partial x_k} \left[\frac{\partial U}{\partial \pi} \right]^{-1}}{w_j - \frac{\partial U}{\partial x_j} \left[\frac{\partial U}{\partial \pi} \right]^{-1}} = \frac{w_k^S}{w_j^S}. \quad (1)$$

Equation 1 highlights the equivalence between utility maximization and shadow cost minimization. The left term equals the marginal rate of technical substitution (MRTS) between inputs i and j . Ignoring the terms involving U , we get the standard cost minimization solution where the firm equates the MRTS to the ratio of market prices. The shadow price ratio and relative price efficiency depend on how responsive utility is to the use of the two inputs under consideration as well as profit. We follow the literature on the agency and team production (Alchian and Demsetz, 1972; Jensen and Meckling, 1976) and assume that for the management input, $\partial U/\partial x < 0$. For the other inputs we assume $\partial U/\partial x \geq 0$ to capture expenditure or firm size maximization preferences. Suppose the management input is indexed by k , then for these assumptions $w_k^S/w_j^S > w_k/w_j$ or $(w_k^S/w_j^S)/(w_k/w_j) > 1$ and the firm employs too little management *relative* to labor. Also, for $\partial U/\partial x_k < 0$ an increase in $\partial U/\partial \pi$ will reduce relative price efficiency, i.e. move towards efficiency, as shown in Appendix A. Finally, if utility is very responsive to profit the shadow price ratio will be close to the competitive price ratio.

Next, we turn to the problem of deriving shadow prices. Shadow prices can be derived from the following shadow cost minimization problem:

$$\begin{aligned}
C^S(W^S, Y) &= \min_X \{W^{S'} X : X \in L(Y)\} \\
\text{s.t. } L(Y) &= \{X \in \mathbb{R}_+^K : X \text{ can produce } Y, \text{ and } Y \in \mathbb{R}_+^Q\},
\end{aligned} \tag{2}$$

where the firm chooses inputs to minimize total shadow cost C^S for given shadow prices W^S . The technology constraint is the input requirement set $L(Y)$, which gives all input vectors for K inputs, i.e., $X \in \mathbb{R}_+^K$, required to produce a vector of Q outputs, i.e., $Y \in \mathbb{R}_+^Q$. This optimization problem only allows the derivation of average relative shadow prices (Atkinson and Halvorsen, 1984, 1986). Färe and Grosskopf (1990) show that using the dual input distance function (Shephard, 1970) allows the derivation of observation-specific relative and absolute shadow prices. Assuming strong disposability, the cost function and the IDF are equivalent representations of the technology. The input distance function (IDF) is:

$$D(X, Y) = \max_{\rho} \{\rho > 0 : (X/\rho) \in L(Y)\}, \quad (3)$$

where ρ is the largest scalar by which the input vector can be deflated and remain in the input requirement set $L(Y)$. Satisfying the constraint implies $D(X, Y) \geq 1$, that is $X \in L(Y)$ if and only if $D(X, Y) \geq 1$. The properties of the IDF are as follows. It is non-increasing in each output level; non-decreasing in each input level; and homogeneous of degree 1 in X . Shephard (1970) shows that the IDF can be derived from a price minimal cost function (a dual of the shadow cost function):

$$D(X, Y) = \min_V \{V'X : C(Y, V) \geq 1\}, \quad (4)$$

For a known distance function (we specify a translog form in the next section) its derivative with respect to X (dual Shephard's lemma) gives V , inverse input demand:

$$\frac{\partial D(X, Y)}{\partial X_k} = v_k, \quad \forall k = 1, \dots, K. \quad (5)$$

Färe and Grosskopf (1990) show that when duality holds $V = W^S/C$, shadow price deflated by minimal cost. We obtain *relative* shadow prices between two inputs k and j as the ratio of the relevant first order conditions from (5):

$$\frac{w_k^S}{w_j^S} = \frac{v_k}{v_j}, \quad \forall k, j = 1, \dots, K. \quad (6)$$

Also, Färe and Grosskopf (1990) show how one can recover absolute shadow prices w_k^S , $\forall k = 2, \dots, K$ when assuming that for one of the inputs the shadow price equals the actual price, i.e. $w_1^S = w_1$. We use labor as the numeraire input assuming that observed wages reflect competitive market prices, i.e. absolute price efficiency prevails for labor. For the other inputs absolute price efficiency is defined as w_k^S/w_k . We use relative shadow prices to calculate relative price efficiencies for inputs k and j as:

$$\kappa_{kj} = \frac{w_k^S/w_j^S}{w_k/w_j}, \quad \forall k, j = 1, \dots, K. \quad (7)$$

Relative price efficiency requires that $\kappa_{kj} = 1$. This is equivalent to saying that ratios of shadow prices (or marginal products) equate to ratios of observed prices. If $\kappa_{kj} > 1$ ($\kappa_{kj} < 1$) input k is under-utilized (over-utilized) relative to input j . Intuitively, this is easiest to see when remembering that the shadow price equals the value of marginal product. If the marginal product of k relative to j is greater than the relevant market price ratio the firm can minimize cost further by substituting input k for input j .

As inverse demand is a function of X (and Y) we can use derivatives of the IDF (as in 5) to derive the Dual Morishima Elasticity of Substitution M , of input k for input j (Blackorby and Russell, 1975, 1981)⁹, as

$$M_{kj} = \frac{\partial \ln \left(w_k^S(\cdot) / w_j^S(\cdot) \right)}{\partial \ln (X_j / X_k)}, \quad \forall k, j = 1, \dots, K. \quad (8)$$

It gives the change in the ratio of shadow prices for a change in the input quantity ratio, holding output constant (net substitution). This dual measure is appropriate in our context because there is no observable market price of management that firms could react to. We define two inputs as *dual* complements if the sign of (8) is positive and *dual* substitutes if the sign is negative.¹⁰ Suppose a firm increases labor j in relation to management k , i.e. the denominator increases. The greater the corresponding increase in the input price (shift in inverse demand) of management relative to that of labor the more complementary, i.e. the more difficult to substitute, the inputs are, and the greater is the value of M . The Morishima elasticity is not symmetric when the number of inputs is greater than two, which is highlighted by the following alternative formulation:

$$M_{kj} = \frac{\partial \ln w_k^S(\cdot)}{\partial \ln X_j} - \frac{\partial \ln w_j^S(\cdot)}{\partial \ln X_j}, \quad (9)$$

where the first term is the partial elasticity of substitution and the second term is

⁹The literature also refers to Indirect Morishima Elasticity of Substitution or Morishima Elasticity of Complementarity.

¹⁰Remember that for a primal/direct Morishima elasticity of substitution larger values indicate a greater ease of substitution, but the primal and dual Morishima elasticities of substitution are not comparable because the measure different things (Mundra and Russell, 2004). For a detailed description of the different elasticities of substitution see Stern (2011) or Russell (2017).

the own quantity elasticity. It also highlights that the partial cross-quantity elasticity does not necessarily have the same sign as the Morishima elasticity. For instance, if two inputs are partial dual complements the first term is positive. If as usual the own-quantity elasticity was negative, the second term would work in the same direction as the first term. If however, the first term was negative, M could have a different sign from the partial cross-quantity elasticity.

The elasticity of substitution gives information about the (technical) difficulty of substitution between two inputs. It indicates the technological constraints under which firms operate. Also, $M_{kj} - 1$ is a comparative static for the relative cost shares of two inputs.¹¹ For M greater (smaller) than one, an increase in input j increases (decreases) the shadow cost share of input k relative to that of input j .

3. Estimation

In this section we show how we can estimate shadow prices and elasticities of substitution as introduced above. For estimation we start with a differentiable input distance function (IDF):

$$D = D(X, Y). \tag{10}$$

To make sure that the IDF represents a generic technology we impose the restriction of homogeneity of degree 1 in inputs, e.g. the distance doubles if all the inputs double, by making X_1 the numeraire input. We re-write (10) as:

$$D \cdot X_1^{-1} = D(\tilde{X}, Y), \tag{11}$$

where \tilde{X} is a vector of input ratios, with elements $\tilde{X}_k = X_k/X_1, \forall k = 2, \dots, K$.

In theory, under variable returns to scale (VRS), the IDF is susceptible to the endogeneity of outputs causing more estimates to violate the theoretical properties of the

¹¹See Russell (2017) for a derivation.

IDF, e.g. negative estimated shadow prices. We impose constant returns to scale (CRS) as this increases the number of estimated shadow prices that satisfy the non-negativity constraint for our data. With one output, CRS guarantees that the output does not appear on the right-hand-side of the IDF and there is no endogeneity issue (Kumbhakar, 2013). We impose homogeneity of degree -1 in Y , using our single output as the numeraire we get

$$D \cdot X_1^{-1} \cdot Y = D(\tilde{X}). \quad (12)$$

To make estimation more convenient we take the natural logarithm on both sides and re-arrange:

$$\ln D = \ln X_1 - \ln Y + d(\ln \tilde{X}), \quad (13)$$

where $d(\ln \tilde{X}) = \ln D(\tilde{X})$. The monotonicity property of the IDF requires that the derivatives (cost deflated shadow prices) have the following signs:

$$\frac{\partial \ln D}{\partial \ln X_1} = 1 - \sum_{k=2}^K \frac{\partial d(\cdot)}{\partial \ln \tilde{X}_k} \geq 0; \quad \text{and} \quad \frac{\partial \ln D}{\partial \ln X_k} = \frac{\partial d(\cdot)}{\partial \ln \tilde{X}_k} \geq 0, \quad \forall k = 2, \dots, K. \quad (14)$$

For estimation we set $D = 1$ (Färe and Grosskopf, 1990), i.e. estimate these derivatives along the technology frontier, impose a flexible translog functional form on $d(\cdot)$ in (13), and add a random noise term ϵ_{it} . Additionally, we include additive firm fixed effects μ_i and a non-linear time trend t . Thus, our technology controls for unobserved firm heterogeneity and allows common technical change across time. Note that even though the management input is time-invariant, all our independent variables are time varying ratios.¹² We estimate:

$$\begin{aligned} -\ln X_{1it} + \ln Y_{it} &= 0 + \sum_{k=2}^K \theta_k \ln \tilde{X}_{kit} + \frac{1}{2} \sum_{k=2}^K \sum_{j=2}^K \theta_{kj} \ln \tilde{X}_{kit} \ln \tilde{X}_{jit} \\ &+ \quad t \quad t + \frac{1}{2} \quad tt \quad t^2 + \sum_{k=2}^K \delta_{kt} \ln \tilde{X}_{kit} \quad t + \mu_i + \epsilon_{it}, \end{aligned} \quad (15)$$

¹²The homogeneity in input constraint is dictated by the property of the IDF, and therefore, must be imposed on the IDF. The homogeneity in input restriction also guarantees that the management input is identified in a model with fixed effects.

where i and t are firm and year indices and $\theta_{kj} = \theta_{jk}, \forall k, j = 2, \dots, K$. From the estimated coefficients we obtain the elasticities:

$$\theta_k = \frac{\partial d(\cdot)}{\partial \ln \tilde{X}_k} = \theta_k + \sum_{j=2}^K \theta_{kj} \ln \tilde{X}_j + \delta_{kt}t, \quad \forall k = 2, \dots, K, \quad (16)$$

and

$$\theta_0 = \frac{\partial d(\cdot)}{\partial t} = \theta_0 + \theta_{tt}t + \sum_{k=2}^K \delta_{kt} \ln \tilde{X}_k. \quad (17)$$

These elasticities are observation specific due to the variability of the data. The economic intuition is that elasticities vary along the iso-quant and potentially due to shifts in the iso-quant across time. Our estimator for (15) is constrained Ordinary Least Squares (OLS). We impose the theoretical constraints in (14), as well as technical progress for (17) by using the constrained weighted bootstrapping (CWB) method for linear parametric models proposed by Parmeter et al. (2014). The advantage of CWB is to allow multiple constraints and to impose them at every point not just the sample mean.

We use the elasticities $\theta_k, \forall k = 2, \dots, K$, to calculate absolute shadow prices, relative price efficiencies, and elasticities of substitution. The empirical equivalent of (6) is:

$$\frac{w_k^S}{w_1^S} = \frac{\theta_k X_1}{\theta_1 X_k}, \quad \forall k = 2, \dots, K. \quad (18)$$

This result holds for constant as well as variable returns to scale technologies (see Appendix B for derivation details). We use (18) to obtain absolute shadow prices, $w_k^S, \forall k = 2, \dots, K$ assuming that $w_1^S = w_1$. Multiplying both sides of (18) by w_1/w_k we obtain relative price efficiencies as in (7). Also, we use (18) to calculate Dual Morishima Elasticities of Substitution as in (8). For both the price efficiency and elasticity of substitution estimates we obtain 95% confidence intervals using a i.i.d. bootstrap. We bootstrap the translog model B=499 times. Then for each observation, we have a sample of $(1 + B)$ estimates, i.e., including the original estimate. The 95% confidence interval for a particular observation is then constructed using the 2.5th and 97.5th per-

centiles from the sample of $(1 + B)$ estimates. See Appendix C for more details on the estimation.

4. Data

In their seminal paper Bloom and Van Reenen (2007) introduce a survey tool, developed in collaboration with a leading management consulting firm, to consistently measure firm-level management practices across firms and countries. The tool defines 18 separate management practices (reproduced in Appendix D). Each practice is scored between 1 (worst) and 5 (best). As it is not clear from the descriptions of individual practices whether they substitute for or complement the conventional inputs, we follow Bloom and Van Reenen (2007) and take the unweighted average across all practices as a continuous measure of management quantity or quality. Like capital and labor, management is an aggregate input, combining different types of management.¹³

The data combines the time-invariant management variable from the survey and matched accounting data from Amadeus for the European countries and Compustat for the US. The data is available online at worldmanagementsurvey.org. On the site there are also related data sets with management observations for more firms and countries. We use data from the original survey wave because it is matched with detailed data on input prices, which are necessary for our analysis. The sample is an unbalanced panel of 505 medium-sized manufacturing firms from the United States, United Kingdom, Germany, and France for the years 1994 to 2004.

From the available accounting data we choose the following proxies for output and input quantities. We measure output Y as value added: deflated sales less material expenses in US dollars. Capital input K is tangible fixed assets in US dollars and labor input L is number of employees. Table 1 provides summary statistics for our input and

¹³As for most measures of capital and labor the use of an aggregate management index requires a separable production technology, i.e. it requires that the marginal rates of substitution between the different management practices do not depend on changes in the capital and labor inputs. The specific restrictions for Morishima elasticities of substitution are discussed by Blackorby and Russell (1976) and Blackorby and Russell (1981).

output variables for all (firm-year) observations for which we are able to estimate the shadow price of management.

The identification of absolute (not relative) shadow prices requires observation of one (competitive) input price. We choose the labor wage, which is available in the data. Also, we use return on capital employed (ROCE, measured as a proportion between 0 and 1) and CEO compensation as proxies for the prices of capital and management, respectively. Using the data on CEO compensation from Bloom and Van Reenen (2007)¹⁴ has the advantage that it is firm specific, but disadvantages are that it is only available for the US sub-sample and that the sample has only 67 observations with all three input prices non-missing. For some of our analysis we replace all observed and missing prices by their country-industry-year means, and refer to “industry average”. Arguably, averages are better measures of firms’ opportunity costs than their individual prices. Also, there are many definitions of CEO compensation and we have no data for the European countries. As an alternative measure of CEO compensation we use data from Edmans et al. (2017).¹⁵ The data is a yearly US average for S&P SmallCap 600 and not firm-specific. We refer to it as “country average”. Table 3 shows that for the US, the average compensation from Bloom and Van Reenen (2007) is only about a third of average compensation from Edmans et al. (2017). This might be because the latter includes more non-salary components or because firms in the S&P SmallCap 600 are larger than firms in our sample. For the remainder we refer to the data from Bloom and Van Reenen (2007) as “salary” and the data from Edmans et al. (2017) as “total compensation”. The data from Edmans et al. (2017) also allows us to infer CEO compensation for the three European countries as they report average CEO compensation for the UK, Germany and France, over the period 2002-2009. We create compensation time series for the European

¹⁴Bloom and Van Reenen (2007, p. 1404) describe the data sources for CEO pay as follows: “In the United States, the S&P 1500 largest firms (which cover all sectors) are contained in Execucomp, which provided data for the 106 largest of our U.S. firms. For the remaining firms, we manually downloaded the Def14a proxy statements from the SEC to extract the details of the CEO compensation package and age over the last three accounting years.”

¹⁵Total compensation is the sum of salary, bonus, payouts from long-term incentive plans, the grant-date value of option grants (calculated using Black-Scholes), the grant-date value of restricted stock grants, and miscellaneous other compensation.

Table 1: Summary Statistics for Inputs and Outputs

	Mean	S.D.	Min.	Max.
Value added (thd. US\$)	98745.00	170192.10	334.68	1499827.00
No. employees	1077.28	1763.58	4.00	16167.00
Capital (thd. US\$)	44225.04	103034.01	26.00	1631268.88
Management (index)	3.13	0.82	1.06	5.00
Observations	2441			

Notes: This table gives summary statistics for the inputs and outputs of the technology.

countries for earlier years by using the proportions relative to US compensation. The proportions relative to US compensation for the UK, Germany, and France are 0.47, 0.63, and 0.51, respectively (Edmans et al., 2017, Table 5).

5. Results

5.1. Shadow prices and absolute price efficiency

Even though absolute prices are not relevant for economic decision making, management's absolute shadow price is of interest, because like for many other intangibles, there is no observable (market) price. Table 2 prints summary statistics for the numeraire price (labor) as well as the estimated shadow prices for capital and management.¹⁶ As man-

¹⁶Table 8 in Appendix E gives the coefficient estimates for our translog input distance function.

Table 2: Summary Statistics for Shadow Prices

	Mean	Median	S.D
Labor (observed)	38.02	35.61	13.24
Capital	0.78	0.55	0.72
Management	1344.75	897.57	1221.76
Observations	2441		

Notes: This table gives summary statistics for the (shadow) input prices. The labor price is the observed (numeraire price). Labor and management shadow prices are in thd. US dollars/year. The shadow price of capital is return on capital employed as a proportion.

Table 3: Average Management Shadow Price and CEO Compensation

	US	Germany	France	UK
Shadow Price	3125	2358	980	1122
Shadow Price (ind. avg.)	2448	2461	706	999
CEO comp.	665	.	.	.
CEO comp. (ctry avg)	1967	1245	1027	916

Notes: The first row gives the mean of estimated shadow price of management for our original data. The second row gives the estimated shadow price of management when we replace all input prices by their country-industry-year averages. The third row gives the original CEO compensation data. The fourth row gives the country average CEO compensation from Edmans et al. (2017).

agement is effectively measured as a continuous index between 1 and 5, the average shadow price suggests that hiring a one-step increase in the management index costs about 1.3 million US dollars per annum. As shadow cost minimization behavior implies that an input's shadow price equals its value of marginal product a one-step increase on the management index has a 1.3 million US dollars marginal benefit per annum, too. The shadow price of management has a relatively large standard deviation.¹⁷ Compared to its mean, the standard deviation is much larger than that of the labor wage and comparable to that of the price of capital. The comparisons of means and medians shows that as typical these prices have long right tails. There is also heterogeneity across countries. The first two rows of Table 3 give average shadow prices by country. Whereas the first row uses observed input prices, the second row uses cell-average input prices and the difference between the two shadow prices is only due to different resulting sample sizes. Across the two rows it is clear that the US and Germany have shadow prices/marginal products of management that are at least twice as large as those for France and the UK.

To check whether our estimated shadow prices are reasonable we can look at the implied shadow cost shares. Table 4 gives summary statistics for the shares. Due to the assumption of constant returns to scale, firm-level cost shares sum to one. Taking 2/3 labor and 1/3 capital shares as the benchmark we see that management's 10 percent

¹⁷There are some very small values but already at the 1st percentile the value is 0.176 million.

Table 4: Summary Statistics for Shadow Cost Shares

	Mean	S.D.	Min.	Max.
Labor	0.63	0.03	0.51	0.74
Capital	0.26	0.01	0.23	0.30
Management	0.10	0.03	0.00	0.25
Observations	2441			

Notes: This table gives summary statistics for the estimated firm-level shadow cost shares.

share comes at the expense of both of them but probably at a slightly larger expense of the labor share. This seems reasonable. Also, management’s shadow cost share is similar to the Cobb-Douglas output elasticities estimated by Bloom et al. (2019, Table 1) for a much larger sample of firms. Finally, the average firm’s management shadow price is about 35 times the average employee’s salary, which again seems reasonable.

To assess a firm’s absolute price efficiency we need to relate the estimated shadow price to some observable proxy. One potential proxy is the price of relevant consulting services. For instance, Bloom et al. (2013) report that the market price for consulting services in an experiment to treat Indian plants with management practices comparable to the practices here is \$250,000.¹⁸ Also, we can relate management’s shadow price to CEO compensation, our preferred proxy for management’s unobserved true price.¹⁹ The two bottom rows of Table 3 give country averages for our two measures of observed CEO compensation. As discussed above both measures of CEO compensation are only available for the US. Absolute price efficiencies vary across countries. Whereas for the US and Germany shadow prices are probably higher than CEO compensation for the UK and France shadow prices are fairly close to total compensation. Our theory of utility maximization suggests that in the UK and France utility is more responsive to profit or utility is reduced less by the use of more management. Alternatively, it is possible that

¹⁸Although, both our data and the Indian experiment use similar categories of structured management practices the indices are not directly comparable and we cannot say that the unit for a one point increase on the index is the same.

¹⁹Data from statistical agencies also gives average earnings for managers, but the wage of a single manager is less likely to reflect the quality of management practices than the wage of the CEO.

compensation is a better proxy for the price of management in these two countries. But remember that absolute price efficiency does not tell us whether firms over or under-utilize management. However, we can calculate total shadow cost and contrast it with total actual cost. We do this for US firms for which we observe firm-level CEO pay. On average a firm could reduce its total cost by 5 percent if it minimized cost subject to observed instead of shadow prices. But this quantitative result crucially depends on CEO pay being the correct measure for management's market price. Below we use relative price efficiencies to analyze whether firms over or under-utilize management. But before, the next section discusses the ease of substitution for management.

5.2. Dual elasticities of substitution

Important for firm decision making is the difficulty of economic input substitution. In this section we describe this difficulty using estimates of partial and ratio elasticities of substitution, which in our dual formulation is the change in (relative) price (inverse demand) that is required to support a quantity change. All our estimates are observation specific and we control for any time-invariant firm-level heterogeneity. Table 5 gives summary statistics for the own-quantity and partial cross-quantity elasticities, the two terms in (9). We remove all values that are greater than absolute two; a maximum of about 0.5 per cent. As labor is our numeraire input, its elasticities are zero, i.e. we assume that in a perfectly competitive labor market the wage does not change with the (own or cross) quantity demanded. As predicted by economic theory, the average own-quantity elasticities for management and capital are negative.²⁰ When a firm increases its use of management, the price of management decreases. Compared to capital an increase in the management quantity requires a smaller reduction in price. We can say the demand for management is more elastic than that for capital. The partial cross-quantity elasticities indicate that on average all input pairs are partial dual complements. For instance, a 1 per cent increase in capital input increases the price (inverse demand) of management by 0.04 per cent.

²⁰For management less than 1 percent of observations violate the sign condition.

Table 5: Summary Statistics for Own and Cross-Quantity Elasticities

	Mean	S.D.	Min.	Max.
Capital	-0.94	0.00	-0.94	-0.93
Management	-0.64	0.15	-0.82	0.67
Management, Capital	0.04	0.03	0.03	0.91
Management, Labor	0.60	0.16	-0.81	0.79
Capital, Management	0.06	0.00	0.05	0.07
Capital, Labor	0.88	0.00	0.86	0.89
Observations	2441			

Notes: This table gives summary statistics for own-quantity and partial cross-quantity elasticities. We remove all values that are larger than absolute 2. Note that as labor is our numeraire input its own-quantity elasticity as well as the elasticities for the labor/management and labor/capital pairs are zero.

These partial cross-quantity elasticities omit income effects and our preferred measure for the difficulty of substitution is the Dual Morishima Elasticities of Substitution (8) instead. We plot histograms for the different input pairs in Figure 1. Remember, that positive (negative) values indicate that two inputs are dual Morishima complements (substitutes). We see that for all input pairs and for almost all observations inputs are dual complements and at the mean this classification is robust to the direction of substitution. The bootstrapped confidence intervals (not shown) reveal that, across all input pairs, only a maximum of 9 per cent of observations have elasticities insignificantly different from zero, i.e. two inputs are neither dual complements nor substitutes. The top left panel shows that complementarity is stronger between management and capital than management and labor. There are a few observations for which management and labor are dual substitutes. The complementarity between management and labor is not surprising as it is typically labor that is “managed”. The strong complementarity between management and capital is consistent with the literature that finds complementarity between ICT capital and organizational practices along a firm’s expansion path (Bresnahan et al., 2002; Bloom et al., 2012). Our results show that complementarity also holds along an iso-quant and for overall capital, especially in the management for capital direction. Not only should a firm improve its management when it hires more

capital, it should also hire more capital when it improves its management.

How much does a change in input quantity change relative income shares? For most observations the elasticity of substitution is less than one and therefore an increase in the input under consideration decreases the relative income share of the other input. For the top left panel the average dual Morishima elasticity of substitution for management for labor is 0.6. Thus, a 1 percent increase in the management input decreases labor's relative income share by 0.4 (0.6-1) per cent. However, for management for capital substitution the average is close to one and for many observations it is larger. An increase in management might increase the income share of capital and it might increase capital's share relative to labor. The top right panel shows that for the opposite direction the difference between capital and labor substitution is smaller, but capital and management are still stronger complements. As all estimates are smaller than one, increases in capital or labor reduce management's relative income share. Finally, the bottom panels compare substitution elasticities between management and non-management inputs. The bottom left panel shows that when substituting for capital, management is a stronger complement than labor. However, the bottom right shows that when substituting for labor, management is a weaker complement compared to capital. The two bottom panels also show that there is much more heterogeneity for the difficulty of substitution for management. We take this as evidence that management is a much more diverse input than capital or labor.

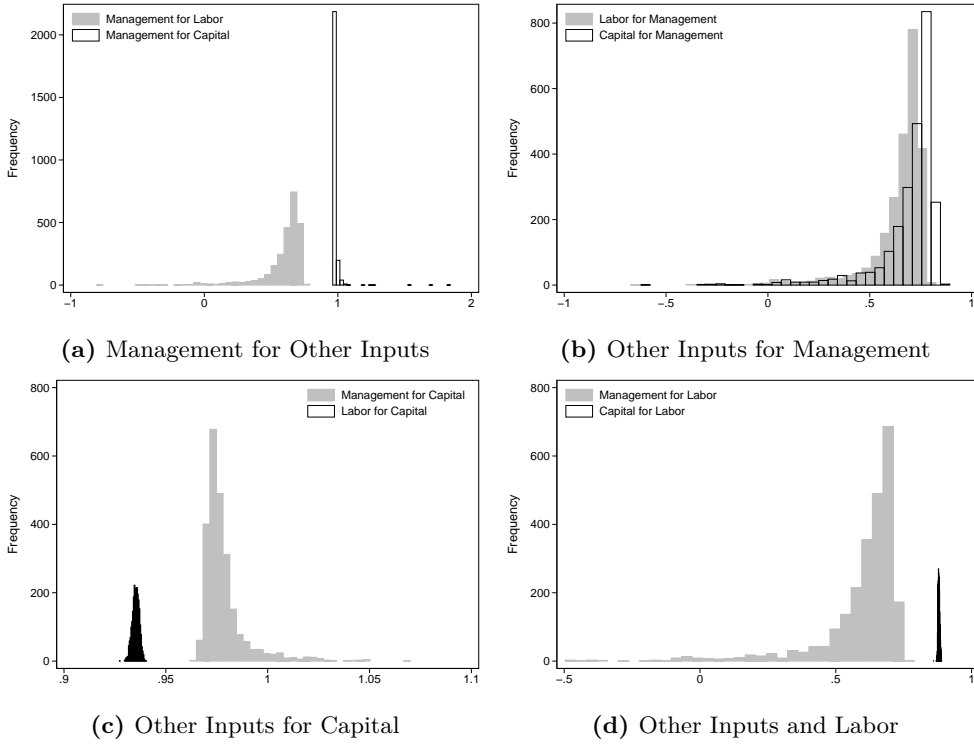


Figure 1: Distribution of Dual Morishima Elasticity of Substitution by Input Pair

Notes: These plots show distributions for the (asymmetric) Morishima elasticities of complementarity.

5.3. Relative price efficiencies

In the previous section we characterized the economic substitution possibilities for different input pairs. Contrasting these with market price ratios allows us to assess whether firms use management efficiently relative to capital or labor. As the necessity to use a proxy for the price of management makes a quantitative assessment of relative price efficiency difficult, we categorize relative price efficiencies κ_{kj} as in (7) depending on whether $\kappa < 1$, i.e. a firm over-utilizes input k relative to input j , $\kappa > 1$, or $\kappa = 1$. The categorization takes into account statistical significance using our bootstrapped 95% confidence intervals. For instance, firms are categorized as over-utilizing k if the confidence interval's upper bound is smaller than one. Table 6 gives numbers and percentages by country and by proxy for the price of management. The top part of the table uses country-industry-year average input prices based on the original data, which has CEO

compensation only for the US. The bottom part also uses country-industry-year average input prices except for management. Instead of CEO compensation from the original data it uses country-year averages from Edmans et al. (2017). As $\kappa_{\text{Capital, Labor}}$ is invariant to the choice of proxy for the price of management we print it only in the top part of the table.

The top row for $\kappa_{\text{Capital, Labor}}$ shows that for all countries, most firms (45%) use efficient ratios of capital and labor, followed by firms that over-utilize capital (34%), and firms that under-utilize capital (21%). It is interesting to contrast $\kappa_{\text{Capital, Labor}}$ with $\kappa_{\text{Management, Labor}}$ and $\kappa_{\text{Management, Capital}}$ in rows two and three for the US. Only a minority of firms uses management efficiently in relation to labor (23%) or capital (29%), which might be because firms themselves do not know the appropriate (shadow) price of management. Most firms use too little management, but a substantive number of them uses too much management, especially in relation to labor (31%). Next, we can compare (again for the US only) $\kappa_{\text{Management, Labor}}$ and $\kappa_{\text{Management, Capital}}$ for the different CEO compensation proxies (rows two and three against rows four and five). Unsurprisingly, as the country-average price is higher, the percentage of firms that over-utilize management is higher, too. The percentage of firms that over-utilizes management relative to labor increases from 31 to 56, and in relation to capital from 15 to 45. How does the efficiency of management's relative use compare across countries? The bottom two rows show that Germany has the largest percentage of firms that use management efficiently relative to labor and the UK has the largest percentage of firms that use management efficiently relative to capital. France has the largest number of firms that over-utilize management in relation to both labor and capital. Whereas US firms have the highest average management score (Bloom and Van Reenen, 2007) they are not necessarily better than their European peers in their *relative* use of management.

5.4. Drivers of relative price efficiency

We saw above that firms differ widely in their relative price efficiencies. What might explain these differences? We investigate three popular drivers for productivity in general:

Table 6: Relative Price Efficiency by Country

Industry Average CEO Compensation										
Capital/Labor	US		Germany		France		UK		Total	
	<i>No.</i>	%	<i>No.</i>	%	<i>No.</i>	%	<i>No.</i>	%	<i>No.</i>	%
$\kappa < 1$	644	50	50	12	168	20	377	35	1,239	34
$\kappa = 1$	597	47	146	35	416	49	467	44	1,626	45
$\kappa > 1$	39	3	218	53	262	31	222	21	741	21
Management/Labor	US		Total							
	<i>No.</i>	%	<i>No.</i>	%						
$\kappa < 1$	397	31	397	31						
$\kappa = 1$	290	23	290	23						
$\kappa > 1$	593	46	593	46						
Management/Capital	US		Total							
	<i>No.</i>	%	<i>No.</i>	%						
$\kappa < 1$	189	15	189	15						
$\kappa = 1$	365	29	365	29						
$\kappa > 1$	718	56	718	56						
Country Average CEO Compensation										
Management/Labor	US		Germany		France		UK		Total	
	<i>No.</i>	%	<i>No.</i>	%	<i>No.</i>	%	<i>No.</i>	%	<i>No.</i>	%
$\kappa < 1$	721	56	132	31	562	65	633	59	2,048	56
$\kappa = 1$	405	32	197	46	262	30	340	32	1,204	33
$\kappa > 1$	154	12	100	23	42	5	105	10	401	11
Management/Capital	US		Germany		France		UK		Total	
	<i>No.</i>	%	<i>No.</i>	%	<i>No.</i>	%	<i>No.</i>	%	<i>No.</i>	%
$\kappa < 1$	573	45	206	49	523	62	467	44	1,769	49
$\kappa = 1$	419	33	176	42	292	34	467	44	1,354	37
$\kappa > 1$	288	23	36	9	32	4	132	12	488	14

Notes: For each input pair the table categorizes relative price efficiencies based on $\kappa < 1$, $\kappa = 1$, or $\kappa > 1$. It gives counts and percentages by country. The top part of the table uses country-industry-year average input prices using the original data. CEO compensation is only available for the US. The bottom part also uses country-industry-year average input prices except for management. CEO compensation is country year averages based on data from Edmans et al. (2017).

time, ownership, and competition.

First, do firms improve relative price efficiency over time? Remember that even though the management input is time-invariant its relative use is not. Figure 2 plots yearly average price efficiencies for the different input pairs. Whereas the top panels give the trends for the US using alternative proxies for the price of management, the lower panel gives the trend for the three European countries. Irrespective of the proxy or the country firms improve their relative use of management over time. Comparing the two top panels we see that, using the higher country average price of management, the relative use of management improves faster and the US firm average achieves relative efficiency towards the end of the sample. For European firms management's relative price efficiency varies less over time. Like in the US $\kappa_{\text{Management, Labor}}$ improves at the beginning of the sample but towards the end of the sample European firms use too much management relative to labor. Whereas in the US average $\kappa_{\text{Capital, Labor}}$ varies very little over time and firms are relatively efficient, in Europe $\kappa_{\text{Capital, Labor}}$ varies a lot and firms increasingly use too little capital in relation to labor.

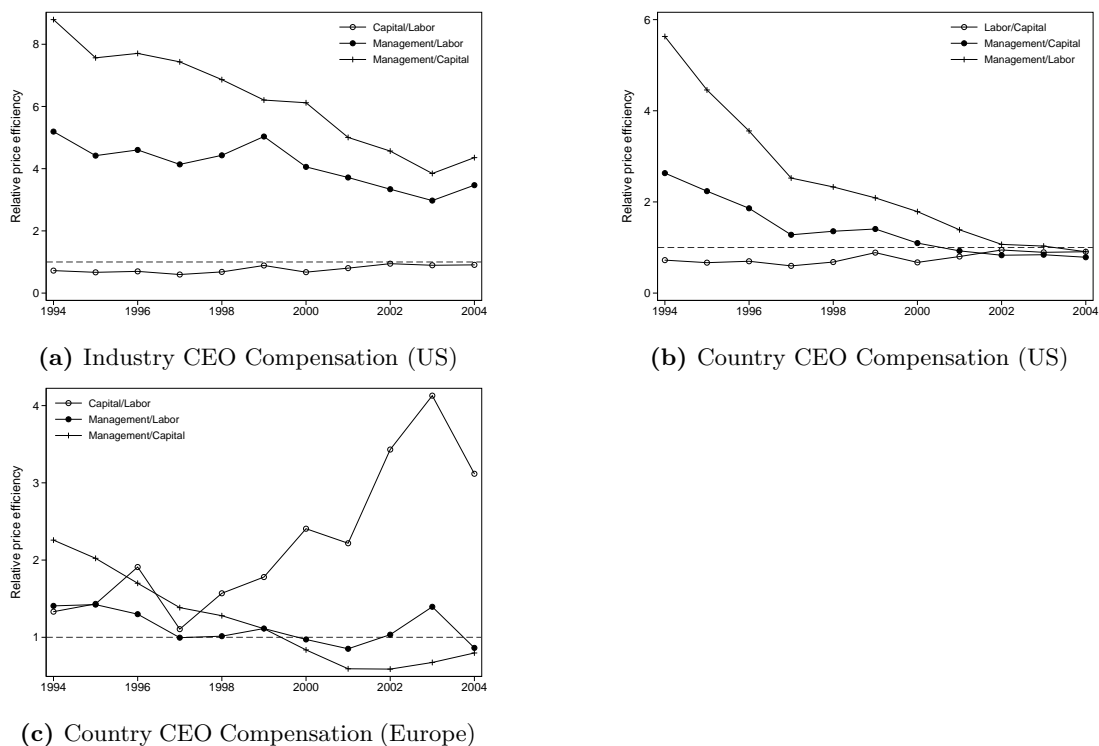


Figure 2: Price Efficiency by Year

Notes: This graph plots average annual relative price efficiencies for the different input pairs. The top left panel uses country-industry-year average input prices using the original data. CEO compensation is only available for the US. The top right and bottom panels also use country-industry-year average input prices except for management. CEO compensation is country year averages based on data from Edmans et al. (2017). Whereas the top right panel is for the US only, the bottom panel is only for Germany, France, and UK.

Second, are firms that separate ownership and control more price inefficient? We consider observed ownership type a proxy for that unobserved separation and thus managers' utility maximizing behavior. Additionally, for some ownership types owners themselves might be utility maximizing (Lemos and Scur, 2019). To highlight inefficiency differences across types, Figure 3 gives average deviations from price efficiency, i.e. $\kappa - 1$, such that values above (below) zero indicate under (over)-utilization of input k relative to j . We give these deviations for the different input pairs as well as the raw management score by ownership type, as defined by Bloom and Van Reenen (2007).²¹ Whereas “founder”

²¹The percentages of observations by ownership type are: family: 10, founder: 18, institution: 56, manager: 3, other: 2, and private: 11.

means first-generation family ownership, “family” means second or later generation family ownership. Also, we compare price efficiencies for our two proxies for the price of management. As above $\kappa_{\text{Capital, Labor}}$ estimates do not depend on that choice. For these comparisons to be meaningful we only use the US sub-sample.

The top panels show that as before $\kappa_{\text{Management, Labor}}$ and $\kappa_{\text{Management, Capital}}$ depend on the proxy for the price of management. When using industry-average compensation all types except “other” under-utilize management. In terms of our theoretical model this would be consistent with utility decreasing in management but increasing in the other input. However, using country-average compensation, “founder”, “manager”, and “other” over-utilize management. There is evidence that types that tend to have a larger separation between ownership and control, are more inefficient. Across the two top panels price inefficiencies are largest for family, institution, and privately-owned firms. We would expect these ownership types to suffer more from agency problems or in the case of family ownership to have utility maximizing owners. A possible explanation for the difference between family and founder owned firms is that later generations, relative to the founding generation, might be more interested in utility maximization (Holtz-Eakin et al., 1993). Also, family as opposed to founder owned firms are more likely to employ outside managers and thus suffer agency problems. The bottom left panel shows average values for $\kappa_{\text{Capital, Labor}}$. All types except “other” use too much capital relative to labor, which would be consistent with utility increasing in both capital and labor. For comparison, the bottom right panel gives average absolute management scores across ownership types. Our theoretical model is silent about differences in absolute management input across types and the pattern is different. For instance “institution” and “private” have relatively high absolute management inputs.²² To conclude, there is evidence that relative price efficiency varies across ownership types as we would expect given common assumptions about utility maximizing behavior across different ownership forms.

²²Bloom and Van Reenen (2007) showed that empirically only family ownership combined with control and CEO selection by primogeniture reduces the absolute management score.

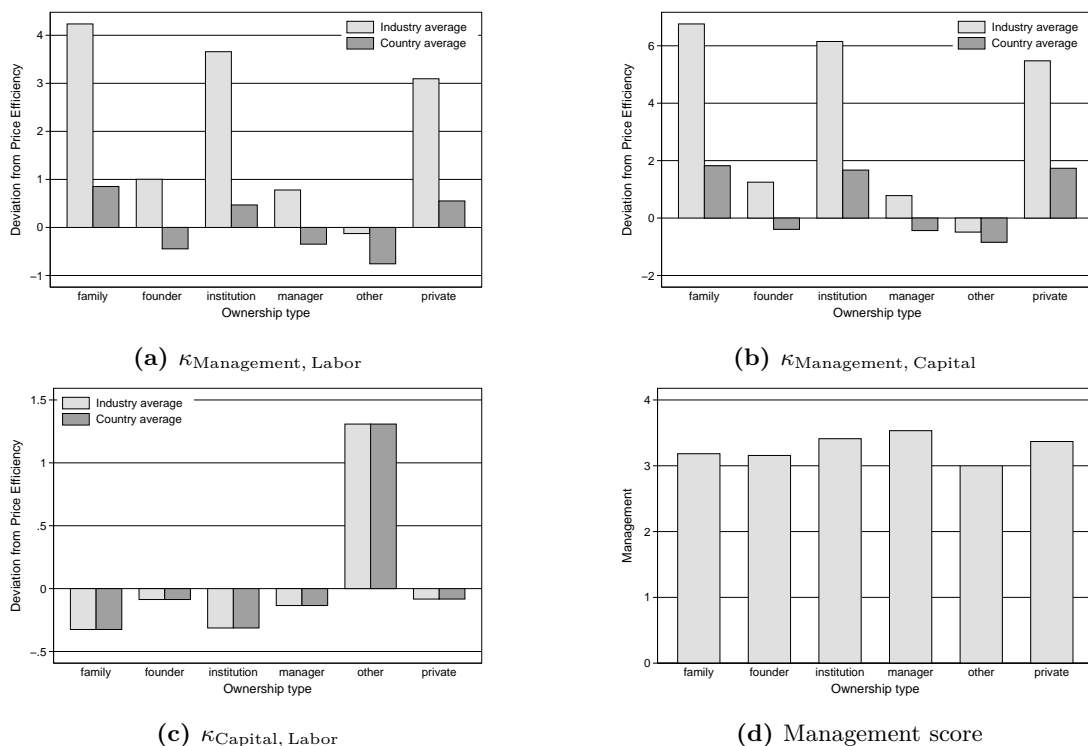


Figure 3: Price Efficiency and Management by Ownership Type

Notes: The top two and bottom left panels show average deviations for relative price efficiency from one (efficiency). Averages are for different input pairs, by firm ownership type, and by management price proxy. Input prices are country-industry-year averages. The price of management is either the “industry average” from the original data or the “country average” from Edmans et al. (2017). The bottom-right panel gives the raw management scores by ownership type. US firms only.

Third, does competition increase relative price efficiency? Figure 4, analogous to Figure 3, gives the average deviation from price efficiency by level of competitiveness. Competitive pressure is measured by an inverse (categorized) Lerner index; higher values indicate more intense competition. The top two panels show that industry competitiveness is positively correlated with relative price efficiency for $\kappa_{\text{Management, Labor}}$ and $\kappa_{\text{Management, Capital}}$. Firms in more competitive industries use management more efficiently relative to labor or capital. This is consistent with our theory when assuming that utility decreases in the use of management (see Appendix A). Also, it is consistent with prior evidence about the relation between competition and absolute management quantity (Bloom and Van Reenen, 2007). The bottom-left panel shows that competition

also reduces the over-utilization of capital relative to labor. Rents from market power seem to lead to excessive capital investment.

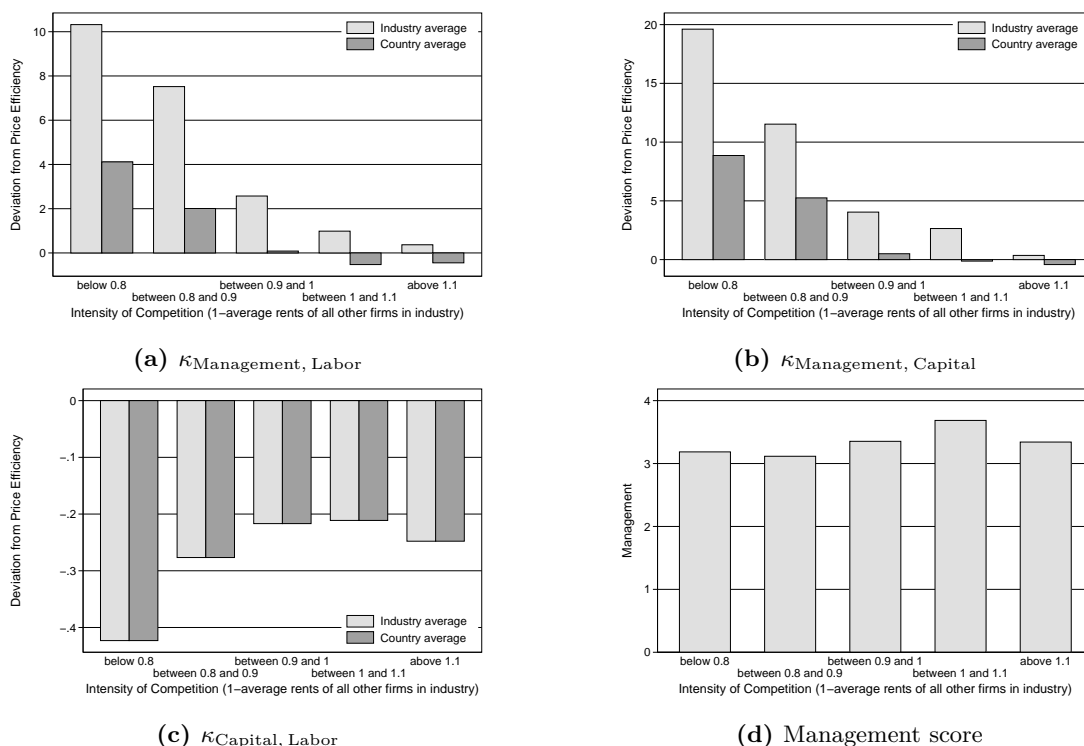


Figure 4: Price Efficiency and Management by Intensity of Competition

Notes: The top two and bottom left panels show average deviations for relative price efficiency from one (efficiency). Averages are for different input pairs, by intensity of competition, and by management price proxy. Intensity of competition is measured by an inverse Lerner index, which is $(1 - \text{profits}/\text{sales})$, calculated as the average across the entire firm population (excluding each firm itself). It is constructed for the period 1995–1999 and is specific to the firm’s country and industry. Input prices are country-industry-year averages. The price of management is either the “industry average” from the original data or the “country average” from Edmans et al. (2017). The bottom-right panel gives the raw management scores by intensity of competition. US firms only.

6. Summary and Conclusion

In this paper we analyze firms’ use of management practices with the help of a model where firms choose the optimal management input to minimize shadow cost subject to shadow prices. The latter equal market prices if firms maximize profit and are subject to a technology constraint only. Although there might be no market price for abstract man-

agement practices, firms, given their objectives, trade-off the implied costs and benefits when deciding on the relative use of management. We derive firm-specific shadow prices from the first order conditions of this optimization problem. Shadow prices (inverse demand functions) allow us to characterize the difficulty of substitution for management and to assess whether firms use management optimally relative to other inputs. As shadow cost minimization is equivalent to utility maximization the model shows how relative optimal use depends on how sensitive utility is to the use of management as well as to profitability.

We find evidence that from the firm's decision making perspective, management is not qualitatively different from capital or labor. Its optimal use depends on relative input prices as well as the constraints under which the firm operates. As predicted, management's own-quantity elasticity is negative and management is a dual Morishima complement for capital (relatively strong) and labor (relatively weak). The degrees of complementarity indicate that when a firm uses more management, the relative income share of labor decreases whereas that of capital might not change or increase. To the extent that top management pay is an important part of the shadow price of management, improving management practices is a source of increasing income inequality between managers and employees as well as between labor and capital. Using CEO compensation as a proxy for the market price (opportunity cost) of management we find that most firms under-utilize management in relation to both capital and labor, but the extent of over-utilization depends on the choice of proxy. Generally, firms do worse optimizing management relative to capital or labor than optimizing capital and labor relative to each other. Firms themselves might not understand the implicit cost of management, but there is evidence they learn over time. Not only does management's relative price efficiency improve with time, inefficiency is also lower for firms that combine ownership and control, and firms in more competitive markets. Taking ownership type as proxy for utility maximization, we find that relative price efficiency varies across types as expected. Founder and manager-owned firms, which tend to combine ownership and control are more efficient in their relative use of management. Finally, we find evidence

that relative price efficiency increases with market competitiveness, consistent with the view that competition increases the sensitivity of utility to profit. Whereas Bloom and Van Reenen (2007) show that firms use too little management in absolute terms, we find that firms also do not employ the optimal amount of management relative to other inputs.

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A. Comparative statics for relative shadow prices

Starting with (1) above

$$\frac{\frac{\partial R}{\partial x_k}}{\frac{\partial R}{\partial x_j}} = \frac{w_k - \frac{\partial U}{\partial x_k} \left[\frac{\partial U}{\partial \pi} \right]^{-1}}{w_j - \frac{\partial U}{\partial x_j} \left[\frac{\partial U}{\partial \pi} \right]^{-1}} = \frac{w_k^S}{w_j^S}$$

we can define relative price efficiency as:

$$\frac{w_k^S w_j}{w_j^S w_k} = \frac{w_k - \frac{\partial U}{\partial x_k} \left[\frac{\partial U}{\partial \pi} \right]^{-1} w_j}{w_j - \frac{\partial U}{\partial x_j} \left[\frac{\partial U}{\partial \pi} \right]^{-1} w_k}.$$

Defining $a = \frac{\partial U}{\partial x_k}$, $c = \frac{\partial U}{\partial x_j}$, and $b = \frac{\partial U}{\partial \pi}$ we can write:

$$\frac{w_k^S w_j}{w_j^S w_k} = \frac{w_k - \frac{a}{b} w_j}{w_j - \frac{c}{b} w_k}$$

and the derivative with respect to b is

$$\begin{aligned} \frac{\partial \left(\frac{w_k^S w_j}{w_j^S w_k} \right)}{\partial b} &= \frac{\frac{a}{b^2} (w_j - \frac{c}{b}) - \frac{c}{b^2} (w_k - \frac{a}{b}) w_j}{(w_j - \frac{c}{b})^2} \frac{w_j}{w_k} \\ &\iff \frac{aw_j - cw_k}{(w_j - \frac{c}{b})^2 b^2} \frac{w_j}{w_k} \end{aligned}$$

as w_j/w_k is positive the sign depends on $aw_j - cw_k$. Thus, whether relative price efficiency increases or decreases with the profit sensitivity of utility depends on the ratio of market prices and how sensitive utility is to input use. If $\frac{a}{c} = \frac{w_k}{w_j}$ relative price efficiency does not depend on profit sensitivity. Suppose utility decreases in management $a < 0$ but increases in the other input $c > 0$. In that case $\frac{a}{c} < \frac{w_k}{w_j}$ and $aw_j - cw_k < 0$. Thus, relative price efficiency decreases, i.e. moves towards efficiency, when the

responsiveness to profit increases.

B. Derivation of shadow prices

This Appendix proves that (18) holds when firms minimize shadow total cost subject to the input distance function. The constrained optimization problem can be written using the same notations as before:

$$\begin{aligned} \min_X W^{S'} X \\ \text{subject to } D = X_1 \cdot D(\tilde{X}, Y, t). \end{aligned} \quad (19)$$

The Lagrangian of the above problem can be written as:

$$\mathcal{L} = W^{S'} X + \lambda [X_1 \cdot D(\tilde{X}, Y, t) - D] \quad (20)$$

where λ is the Lagrange multiplier. The first-order conditions are:

$$\frac{\partial \mathcal{L}}{\partial X_1} = w_1^S + \lambda \left[D(\cdot) + \frac{\partial D(\cdot)}{\partial X_1} \cdot X_1 \right] = 0 \quad (21)$$

and

$$\frac{\partial \mathcal{L}}{\partial \tilde{X}_k} = w_k^S + \lambda \left[X_1 \cdot \frac{\partial D(\cdot)}{\partial \tilde{X}_k} \cdot \frac{\partial \tilde{X}_k}{\partial X_k} \right] = 0, \quad \forall k = 2, \dots, K. \quad (22)$$

The above first-order conditions can be re-written as:

$$w_1^S + \lambda \left[D(\cdot) - \sum_{k=2}^K \frac{\partial D(\cdot)}{\partial \tilde{X}_k} \tilde{X}_k \right] = 0 \quad (23)$$

and

$$w_k^S + \lambda \cdot \frac{\partial D(\cdot)}{\partial \tilde{X}_k} = 0, \quad \forall k = 2, \dots, K, \quad (24)$$

respectively. We can simplify them as

$$\frac{w_k^S}{w_1^S} = \frac{\partial D(\cdot) / \partial \tilde{X}_k}{D(\cdot) - \sum_{k=2}^K \frac{\partial D(\cdot)}{\partial \tilde{X}_k} \tilde{X}_k}, \quad \forall k = 2, \dots, K. \quad (25)$$

Multiply both sides of (25) by X_k/X_1 , and then divide the numerator and denominator of the right-hand-side of (25) by $D(\cdot)$, and we would have:

$$\frac{X_k w_k^S}{X_1 w_1^S} = \frac{k}{1 - \sum_{k=2}^K k}, \quad \forall k = 2, \dots, K, \quad (26)$$

where $k = \frac{\partial D/D}{\partial \tilde{X}_k/\tilde{X}_k} = \frac{\partial \ln D}{\partial \ln \tilde{X}_k}$ is the elasticity of the IDF with respect to input ratios by definition. Equivalently,

$$\frac{w_k^S}{w_1^S} = \frac{k X_1}{1 X_k}, \quad \forall k = 2, \dots, K,$$

where $1 = 1 - \sum_{k=2}^K k$.

C. Elasticity calculation

The Dual Morishima Elasticity of Substitution can be written as the sum of the cross and own quantity elasticities:

$$M_{kj} = \frac{\partial \ln w_j^S}{\partial \ln X_k} - \frac{\partial \ln w_k^S}{\partial \ln X_k}, \quad \forall k, j = 1, \dots, K. \quad (27)$$

To calculate these elasticities, we take the natural logs of both sides of (18) and get:

$$\ln w_k^S = \ln p_k + \ln X_1 + \ln w_1^S - \ln p_1 - \ln X_k, \quad \forall k = 2, \dots, K. \quad (28)$$

The following own and cross quantity elasticities are then obtained under the translog specification:

$$\frac{\partial \ln w_k^S}{\partial \ln X_k} = \frac{\theta_{kk}}{k} + \frac{1}{1} \sum_{j=2}^K \theta_{jk} - 1, \quad \forall k = 2, \dots, K, \quad (29)$$

$$\frac{\partial \ln w_k^S}{\partial \ln X_1} = 1 - \frac{1}{k} \sum_{j=2}^K \theta_{kj} - \frac{1}{1} \sum_{k=2}^K \sum_{j=2}^K \theta_{kj}, \quad \forall k = 2, \dots, K, \quad (30)$$

and

$$\frac{\partial \ln w_j^S}{\partial \ln X_k} = \frac{\theta_{jk}}{j} + \frac{1}{1} \sum_{k'=2}^K \theta_{k'k}, \quad \forall k, j = 2, \dots, K, \text{ and } k \neq j. \quad (31)$$

In addition, $\frac{\partial \ln w_1^S}{\partial \ln X_k} = 0, \forall k = 1, \dots, K$, for the reason that w_1^S is the shadow price of the numeraire input.

D. Survey Questions

Table 7: The Management Practice Dimensions

Categories	Score from 1-5 based on:
1) Introduction of modern manufacturing techniques	What aspects of manufacturing have been formally introduced, including just-in-time delivery from suppliers, automation, flexible manpower, support systems, attitudes, and behavior?
2) Rationale for introduction of modern manufacturing techniques	Were modern manufacturing techniques adopted just because others were using them, or are they linked to meeting business objectives like reducing costs and improving quality?
3) Process problem documentation	Are process improvements made only when problems arise, or are they actively sought out for continuous improvement as part of a normal business process?
4) Performance tracking	Is tracking ad hoc and incomplete, or is performance continually tracked and communicated to all staff?
5) Performance review	Is performance reviewed infrequently and only on a success/failure scale, or is performance reviewed continually with an expectation of continuous improvement?
6) Performance dialogue	In review/performance conversations, to what extent is the purpose, data, agenda, and follow-up steps (like coaching) clear to all parties?
7) Consequence management	To what extent does failure to achieve agreed objectives carry consequences, which can include retraining or reassignment to other jobs?
8) Target balance	Are the goals exclusively financial, or is there a balance of financial and nonfinancial targets?
9) Target interconnection	Are goals based on accounting value, or are they based on shareholder value in a way that works through business units and ultimately is connected to individual performance expectations?
10) Target time horizon	Does top management focus mainly on the short term, or does it visualize short-term targets as a “staircase” toward the main focus on long-term goals?
11) Targets are stretching	Are goals too easy to achieve, especially for some “sacred cows” areas of the firm, or are goals demanding but attainable for all parts of the firm?
12) Performance clarity	Are performance measures ill-defined, poorly understood, and private, or are they well-defined, clearly communicated, and made public?
13) Managing human capital	To what extent are senior managers evaluated and held accountable for attracting, retaining, and developing talent throughout the organization?
14) Rewarding high performance	To what extent are people in the firm rewarded equally irrespective of performance level, or are rewards related to performance and effort?
15) Removing poor performers	Are poor performers rarely removed, or are they retrained and/or moved into different roles or out of the company as soon as the weakness is identified?
16) Promoting high performers	Are people promoted mainly on the basis of tenure, or does the firm actively identify, develop, and promote its top performers?
17) Attracting human capital	Do competitors offer stronger reasons for talented people to join their companies, or does a firm provide a wide range of reasons to encourage talented people to join?
18) Retaining human capital	Does the firm do relatively little to retain top talent or do whatever it takes to retain top talent when they look likely to leave?

Note: This table is reproduced from Bloom and Van Reenen (2010).

E. Regression Estimates

Table 8 gives the coefficient estimates from our translog distance function in (15). The subscripts K, M, and t stand for Capital, Management and time, respectively.

Table 8: Regression results

	Estimate	Std. Error	t value	Pr(> t)
α_0	4.1732	0.3932	10.6129	0.0000
ϑ_K	0.2235	0.1381	1.6180	0.1058
ϑ_M	0.2453	0.1197	2.0491	0.0406
α_t	-0.0082	0.0156	-0.5302	0.5961
ϑ_{KK}	0.0114	0.0265	0.4314	0.6662
ϑ_{KM}	0.0020	0.0183	0.1084	0.9137
δ_{Kt}	0.0019	0.0022	0.8618	0.3889
ϑ_{MM}	0.0284	0.0219	1.2940	0.1958
δ_{Mt}	-0.0003	0.0022	-0.1160	0.9077
α_{tt}	0.0046	0.0012	3.7274	0.0002

Notes: This table gives the coefficient estimates for our translog distance function.