

Why Leverage Affects Pricing

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We explain and provide evidence for effects of leverage on pricing. Our model identifies two effects that either counteract or reinforce each other, depending on the debt maturity structure: (i) firms set higher prices (underinvest in market share) if they have more debt, and (ii) firms engage in dynamic risk-shifting by setting lower (higher) prices if the current debt obligation will be higher (lower) in the next period than in the present period. Using a unique dataset of owner-managed hotels in Austrian ski resorts, we provide empirical evidence of both effects. (*JEL* D43, G31, L83)

1. Introduction

When a firm decides how to price its products or services this decision affects not only the returns to the firm's owners, but also the firm's ability to service its debt. Pricing decisions thus involve trade-offs between the interests of a firm's owners and its creditors. Stylized facts suggest that highly levered firms approach such trade-offs differently than do firms with low leverage. In a number of industries and markets, price levels have changed after key players raised their leverage through recapitalizations.¹ Moreover, a common view among practitioners is that financially distressed firms tend to deviate from value-maximizing pricing policies in order to generate cash at the expense of going-concern value.²

Despite evidence of a relation between firms' pricing policies and their financial structures, the exact nature of the relation has been difficult to decipher.

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¹ For example, Phillips (1995); Chevalier (1995); and Zingales (1998) document such effects.

² See Borenstein and Rose (1995) for a discussion regarding the airline industry.

One reason for this difficulty is that there are confounding effects, the interaction of which depends on the nature of an industry's competitive environment.³ It is also quite difficult to separate effects of leverage on firms' pricing policies from effects of managerial agency problems. This is particularly true in situations where a firm changes its pricing policy following simultaneous changes in the firm's financial structure and its governance.

In this paper, we analyze effects of leverage on firms' pricing strategies, with a focus on the role of the debt maturity structure. We identify two effects, and we show that the maturity structure of a firm's debt determines whether the effects counteract or reinforce each other. We then provide empirical evidence of both effects, thus identifying reasons why firms' pricing policies depend on their financial structures.

We begin our analysis by proposing a model that combines and extends previous theoretical analyses of the relation between firms' financial structures and their pricing policies. Our starting point is Myers' (1977) underinvestment effect. In the presence of default risk, a firm underinvests in positive net present value projects since its owners discount future cash flows at a higher rate than if there is no default risk. Our analysis of this effect builds on the work of Dasgupta and Titman (1998), who model firms' pricing policies in terms of the implicit investments in market share that firms undertake if they reduce their prices.⁴ Such investments are beneficial to a firm's current owners only if the firm does not default. Firm owners thus discount expected investment proceeds at an effective rate that is increasing in the probability of default. A higher default probability leads owners to invest less in market share, i.e., to set higher prices.

We extend the model in order to capture a second effect of leverage on a firm's pricing policy. This second effect exists because an increase in a firm's market share raises the firm's exposure to demand shocks, thus increasing the riskiness of its profits. This increase in riskiness increases the expected return to firm owners because, in the presence of debt, the owners' payoff is a convex function of the firm's profit. Owners thus have incentives to increase the firm's market share in order to engage in "risk shifting." We show that the optimal *timing* of this risk-shifting is determined by the firm's debt maturity structure: this risk-shifting incentive leads owners to invest more in market share if the firm's debt due will be higher in the next period than in the present period.

³ Phillips (1995) documents that leverage has different effects on the product market strategies of firms in different industries. Such cross-industry differences may be due to differences in the ease of new entry (Phillips, 1995), the nature of the competition between the incumbents and the type of uncertainty that exists in the output market (Showalter, 1995), the extent of heterogeneity in firms' financial structures (Phillips, 1995; Chevalier, 1995), the likelihood of price wars (Bolton and Scharfstein, 1990), effects of a firm's leverage on the demand for its product (Titman, 1984; Maksimovic and Titman, 1991; Opler and Titman, 1994; and Campello and Fluck, 2005, etc.

⁴ Chevalier and Scharfstein (1996) also develop a model that relates firms' pricing policies to their financial structures. Both models build on the work of Klemperer (1987) who pointed out that, if habit formation makes it costly for a firm's customers to stop buying the firm's product, then the firm's pricing decisions can be interpreted as decisions to (dis-)invest in market share.

We call this effect the “dynamic limited-liability” (DLL) effect. The effect is a dynamic form of risk-shifting that can either counteract or reinforce the underinvestment effect. The DLL effect counteracts the underinvestment effect if the present period’s debt due is lower than the debt that will be due in the following period. Otherwise, the two effects reinforce each other.

Our theoretical analysis implies that we cannot expect a constant relationship between firms’ debt levels and their pricing decisions, even for firms that are governed in similar ways and operate in the same industry. Because of the existence of two potentially counteracting effects of leverage on a firm’s pricing policy, our empirical analysis must go beyond simply measuring the overall effect. Thus, rather than simply regress prices on a measure of leverage such as debt-to-asset ratios, we specify an empirical model that explains firms’ pricing decisions using proxies for the underinvestment effect and the DLL effect. These proxies follow directly from our theoretical analysis.

We conduct our empirical analysis using a sample of firms that are exposed to a form of demand uncertainty that is similar to that in our theoretical model. These firms are hotels in Austrian ski resorts. They face demand shocks that are due to uncertain snow conditions. Corresponding to our model, these demand shocks occur after the firms set their prices. Moreover, we can measure the extent of a firm’s exposure to demand uncertainty since this exposure depends mainly on the altitude of the closest ski resort. Finally, we can be reasonably certain that the hotels’ pricing strategies are not subject to managerial agency problems, or effects of strategic interaction between firms. All of the firms in our sample are owner-managed businesses that operate in similar regional markets, typically competing against many other owner-managed hotels.

Our estimates provide direct evidence of both the underinvestment effect and the DLL effect. We, thus, document two reasons why leverage affects pricing. First, the higher the default probability, the higher is the effective discount rate that a firm’s owner uses to value the expected future profits resulting from an investment in market share. This effective increase in the discount rate causes the underinvestment effect. Second, the owner has incentives to engage in risk-shifting, and an investment in market share shifts risk exposure from the current to the next period. The firm’s pricing policy depends on the maturity structure of its debt since the owner has incentives to invest in market share if the next-period default probability is higher than the current-period default probability. Thus, if the default probability is increasing over time, then the underinvestment effect is ameliorated, but if the default probability is decreasing over time, then the underinvestment effect is aggravated. This effect is the DLL effect.

To our knowledge, we provide the first empirical validation of a “limited-liability effect” of leverage on firms’ objective functions. The limited-liability effect that we identify is a dynamic effect that depends on the maturity structure of a firm’s debt, rather than just on its debt level. Our dynamic view of the limited-liability effect reveals that the direction of the effect typically varies over time, while one-period models suggest that the direction of the effect is

determined by time-invariant characteristics of a firm's industry.⁵ In addition, we show that the effect interacts with an underinvestment effect of leverage on firms' pricing decisions, i.e., the effect proposed by Dasgupta and Titman (1998).

Our empirical analysis builds on seminal work of Phillips (1995); Chevalier (1995); Chevalier and Scharfstein (1996); and Zingales (1998). All of these papers present evidence that leverage affects firms' pricing decisions; our analysis explores possible reasons for such effects. The results matter for future empirical research. We show that a model of firms' pricing decisions should include not only measures of leverage as explanatory variables, but also proxies for debt maturity such as the ratio of long-term to short-term debt. The latter variables should be included in interaction terms together with measures of leverage. Similar variables should also be used in models that explain effects of leverage on firms' market shares or sales performance.

The remainder of the paper is structured as follows. In Section 2, we present our theoretical model. Section 3 describes the empirical analysis. Section 4 concludes.

2. Effects of Leverage on Pricing—The Model

We consider an industry of firms with similar, but differentiated products. Customers are price sensitive when they choose for the first time among different firms' products. Once a customer has chosen to do business with a particular firm, then the customer remains loyal to that firm in the future. Firms can vary their prices across time, but they cannot discriminate at any point in time between first-time and repeat customers. By setting a lower price today, a firm attracts additional first-time customers and thus effectively invests in its customer base. Our model is of a single representative firm in this industry.

The timeline: There is an infinite number of discrete periods. In each period, t , the firm's owner first chooses the price, p_t , for a unit of the firm's product. Next, demand $\tilde{q}_t$ and profits $\tilde{x}_t$ are realized. If the profit realization x_t exceeds the debt that is due in that period, d_t , then the owner receives the difference, $x_t - d_t$. If $x_t < d_t$, then the owner must decide whether to inject capital into the firm, or allow ownership of the firm to revert to the debtholders.

The owner's objective: The firm's owner is risk-neutral and values future income using a discount factor of β , $0 < \beta < 1$. The owner is not personally liable for the firm's debt. The firm's pricing policy is therefore chosen to maximize the sum across time of $\beta^t E[\max[\tilde{x}_t - d_t, 0]]$ net of the present value

⁵ One-period models have been proposed by Brander and Lewis (1986); Maksimovic (1986); and Showalter (1995). Analyses inspired by these papers include Faure-Grimaud (2000) and Povel and Raith (2004). Oechssler and Schumacher (2004) test the predictions of Brander and Lewis (1986) and Showalter (1995) based on an experimental duopoly market.

of any cash infusions that the owner expects to make in order to maintain ownership of the firm. The firm does not retain any profits.⁶ The sequence $\{d_t\}_{t=1}^{\infty}$ is exogenously given.⁷

Demand: The demand for the firm's output is given by

$$\tilde{q}_t = q_t^* \tilde{\alpha}_t = (\lambda q_{t-1}^* + n^*[p_t]) \tilde{\alpha}_t, \quad (1)$$

where q_t^* is the size of the firm's customer base, given by a deterministic function $q^*[p_t, q_{t-1}^*] = \lambda q_{t-1}^* + n^*[p_t]$.⁸ This customer base includes all former customers of the firm that survive from period $t - 1$ to period t , as well as new customers. The group of surviving customers has size λq_{t-1}^* , where $\lambda \in (0, 1)$ is a constant survival rate. The number of new customers is $n^*[p_t]$, where $n^*[\cdot]$ is a decreasing and differentiable function. $\tilde{\alpha}_t$ is the average demand per customer in period t , given by a positive random variable that is identically and independently distributed across periods, with a distribution F .

The profit function: The firm's profit in period t is given by

$$\tilde{x}_t = (p_t - c_t) q_t^* \tilde{\alpha}_t = x_t^* \tilde{\alpha}_t, \quad (2)$$

where c_t is the exogenously given unit cost. Equation (2) highlights a distinguishing feature of our model: the profit $\tilde{x}_t$ is the product of a deterministic component, x_t^* , and a stochastic component, $\tilde{\alpha}_t$. Thus, the profit is a multiplicatively separable function of price and uncertainty. The deterministic component of the profit function is given by the function $x^*[p_t, q_{t-1}^*] = (p_t - c_t) q^*[p_t, q_{t-1}^*]$. This function is assumed to be concave in p_t . The form of the profit function (2) implies that an increase in the firm's customer base increases the riskiness of the firm's profit. Thus, investing in market share is a form of risk taking. The pricing policy of the firm is affected by the firm owner's incentives to engage in "risk-shifting," so as to benefit from holding a convex claim on the firm's profit. This characteristic distinguishes our model from that of Dasgupta and Titman (1998) who assume that the firm owner's return is an additively separable function of price and uncertainty.

2.1 The optimal pricing policy

If $x_t \geq d_t$, then the firm's owner receives a dividend of $x_t - d_t$ and retains ownership of the firm. If $x_t < d_t$, then the owner can either pay the shortfall,

⁶ This assumption is without loss of generality. The firm's owner optimally withdraws all earnings, since any retained profits would belong to the firm's creditors if the firm defaults in the future.

⁷ In this paper, we do not make any claims as to the optimal level of debt financing. Because our model captures two, possibly offsetting, effects of leverage on pricing policy, debt financing may be (weakly) optimal. We take the firm's financial structure as given since the firms in our sample are typically quite constrained when they attempt to optimize their financial structures. See Section 3 for further discussion.

⁸ The superscript of q_t^* indicates that this is a variable that we cannot observe in a direct way when we take our model to the data.

$d_t - x_t$, or let the firm default and walk away with nothing. The optimal decision depends on the value of the firm's equity. Let V_{t+1} denote the equity value at the start of period $t + 1$, provided that d_t is paid in full. For all realizations of $\tilde{x}_t$, such that $x_t < d_t$, the owner will optimally pay the shortfall if, and only if, $\beta V_{t+1} \geq d_t - x_t$. Using Equation (2), we can restate this condition as: $\alpha_t \geq \underline{\alpha}_t$, where α_t is a realization of $\tilde{\alpha}_t$ and $\underline{\alpha}_t = \underline{\alpha}[p_t, q_{t-1}^*, d_t, V_{t+1}]$ is defined by the equation

$$d_t - \underline{\alpha}_t x^*[p_t, q_{t-1}^*] = \beta V_{t+1}. \quad (3)$$

We refer to $\underline{\alpha}_t$ as the “default trigger” level of demand per customer.

The value of the firm's equity is given by the following Bellman equation:

$$V_t[q_{t-1}^*] = \max_{p_t} \int_{\underline{\alpha}_t} (\alpha_t x^*[p_t, q_{t-1}^*] - d_t + \beta V_{t+1}[q^*[p_t, q_{t-1}^*]]) dF, \quad (4)$$

where the integral is calculated over the nondefault states, $\alpha_t \geq \underline{\alpha}_t$, since the owner's payoff equals zero in the event of default. In the Appendix, we solve this equation and show that the optimal pricing policy satisfies the following Euler condition:

$$MRIS_t DLL_t = (1 - F[\underline{\alpha}_{t+1}]) \beta / \epsilon_{t+1}, \quad (5)$$

where

$$MRIS_t = - \left(\frac{dx_t^*}{dp_t} \right) / \left(\frac{\partial x_{t+1}^*}{\partial q_t^*} \frac{dq_t^*}{dp_t} \right), \quad (6)$$

$$DLL_t = \frac{E[\tilde{\alpha}_t | \alpha_t \geq \underline{\alpha}_t]}{E[\tilde{\alpha}_{t+1} | \alpha_{t+1} \geq \underline{\alpha}_{t+1}]}, \quad (7)$$

$$\epsilon_{t+1} = 1 - (dx_{t+1}^*/dp_{t+1})(1/q_{t+1}^*), \text{ and} \quad (8)$$

$(1 - F[\underline{\alpha}_{t+1}])$ is the probability that the firm doesn't default in period $t + 1$. Each of these term is intuitively described below.

$MRIS_t$ is the marginal rate of intertemporal substitution between the firm's profits in the periods t and $t + 1$, i.e., the current and the next period. The numerator of this ratio, $dx_t^*/dp_t = (d/dp_t)x^*[p_t, q_{t-1}^*]$, is the rate at which the deterministic component of the firm's current profits changes with its current price. If the current price were chosen only with regard to maximizing current profits, then the first-order condition would require that $dx_t^*/dp_t = 0$, and, therefore, that $MRIS_t = 0$. The owner would, for example, set the price so that $MRIS_t = 0$, if β were equal to zero so that the firm's owner puts no value on future income. If, however, the owner trades off current against future income, then the firm will reduce its current price in order to enlarge its customer base.

In this case, $dx_t^*/dp_t > 0$, $MRI S_t > 0$ and $MRI S_t$ represents the marginal-cost–marginal-benefit ratio of the price reduction.⁹

Equation (5) characterizes the optimal pricing policy by specifying an optimal value for $MRI S_t$. The higher this value, the higher the profit reduction that the firm optimally tolerates in the current period in order to increase its next-period profit. The optimal value of $MRI S_t$ is thus a proxy for the optimal level of the firm's current investment in its customer base. As such, it is inversely related to the optimal current period price, p_t .

If the owner's objective were to maximize firm value, then the optimal pricing policy would be specified by: $MRI S_t = \beta/\epsilon_{t+1}$. This condition implies that the firm should invest less in customer base the smaller the discount factor β , and the higher the factor ϵ_{t+1} . The inclusion of ϵ_{t+1} in condition (5) ensures that the pricing policy is consistent through time, i.e., consistent with optimizing behavior beyond the current period.¹⁰

The owner's objective, however, is not to maximize firm value, but rather his own expected payoff. This distinction is important because the owner is not personally liable for the firm's debt, and so the firm's profit affects the owner's payoff only in the nondefault states. It is for this reason that the factors $(1 - F[\underline{\alpha}_{t+1}])$ and DLL_t appear in condition (5). In what follows, we present an intuitive explanation of these factors, and describe how they affect the firm's optimal pricing policy.

The owner calculates the expected cost and benefit of a price reduction. The expected cost is a reduction in the owner's expected payoff in the current period. This expected payoff can be written as $A_t[\underline{\alpha}_t]x_t^*$, where

$$A_t[\underline{\alpha}_t] \equiv (1 - F[\underline{\alpha}_t]) E[\tilde{\alpha}_t | \alpha_t \geq \underline{\alpha}_t]. \quad (9)$$

The first term on the right-hand side is the probability that the firm does not default in the current period; the second term is the expected current period demand per customer, conditional on not defaulting.

The expected benefit of a price reduction in the current period is an increase in the expected future payoff to the firm's owner. The expected next period payoff can be written as $A_{t+1}[\underline{\alpha}_t, \underline{\alpha}_{t+1}]x_{t+1}^*$, where

$$A_{t+1}[\underline{\alpha}_t, \underline{\alpha}_{t+1}] \equiv (1 - F[\underline{\alpha}_t])(1 - F[\underline{\alpha}_{t+1}])E[\tilde{\alpha}_{t+1} | \alpha_{t+1} \geq \underline{\alpha}_{t+1}]. \quad (10)$$

As discussed above, a price reduction in the current period results in a lower value for x_t^* and a higher value for x_{t+1}^* . All else equal, such a price reduction is

⁹ $dx_t^*/dp_t > 0$ since we have assumed that x_t^* is a concave function of p_t , and the firm invests in customer base by choosing a price p_t below the price that maximizes the firm's single-period profit. At any such price, $MRI S_t > 0$ as long as $dx_{t+1}^*/dp_t = (\partial x_{t+1}^*/\partial q_t^*)(dq_t^*/dp_t) < 0$. This latter condition holds as long as $\partial x_{t+1}^*/\partial q_t^* = p_{t+1} - c_{t+1} > 0$. We focus on this case since we find no instance in our sample of pricing below variable costs.

¹⁰ $1/\epsilon_{t+1}$ is a proxy for the extent to which the owner plans to invest in customer base in the period $t + 1$. $\epsilon_{t+1} = 1$ indicates that no investment is planned since $\epsilon_{t+1} = 1$ is the first-order condition for choosing the price p_{t+1} that maximizes the firm's period $t + 1$ profit. If, instead, the firm plans to reduce the price p_{t+1} in order to invest in its customer base, then the concavity of x_{t+1}^* in p_{t+1} implies that $\epsilon_{t+1} < 1$ (since $dx_{t+1}^*/dp_{t+1} > 0$ at the reduced price).

beneficial for the owner if $A_{t+1}[\underline{\alpha}_t, \underline{\alpha}_{t+1}]$ exceeds $A_t[\underline{\alpha}_t]$. When comparing the terms $A_t[\underline{\alpha}_t]$ and $A_{t+1}[\underline{\alpha}_t, \underline{\alpha}_{t+1}]$, we see that the current nondefault probability, $(1 - F[\underline{\alpha}_t])$, appears in both. It is thus only the last term of Equation (9) and the last two terms of Equation (10) that affect the firm's pricing policy. These are the terms that capture effects of leverage on the firm's pricing policy, as discussed below.

The underinvestment effect: If the firm defaults, then the owner cannot profit from an increase in the firm's customer base. For this reason, the owner's willingness to invest in the customer base (by lowering the current price) is increasing in the nondefault probability, $(1 - F[\underline{\alpha}_{t+1}])$. Condition (5) captures this effect by stipulating a positive relation between $(1 - F[\underline{\alpha}_{t+1}])$ and the value of $MRIS_t$. This relation is referred to as the "underinvestment effect," because default risk (a strictly positive value of $F[\underline{\alpha}_{t+1}]$) induces the firm to set a higher price and thus underinvest in its customer base, as if the profits from such an investment are discounted at a higher rate.¹¹

The dynamic limited-liability (DLL) effect: The relative value of the final terms in Equations (9) and (10) appears in condition (5) as the DLL factor, defined in Equation (7). If $DLL_t > 1$, then condition (5) holds for a smaller value of $MRIS_t$ than without the adjustment factor DLL_t . As discussed above, a smaller value of $MRIS_t$ means that the firm decreases its investment in customer base by raising its current price. If $DLL_t < 1$, then the opposite occurs: the firm increases its current investment in customer base by lowering its current price. This relation between the value of DLL_t and the optimal current price is the "dynamic limited-liability (DLL) effect."

The DLL effect follows from the incentive of the firm's owner to engage in "risk shifting," so as to benefit from holding a convex claim on the firm's profit. This risk-shifting incentive affects the firm's pricing policy since a change in the firm's current price has opposite effects on the firm's exposure to demand uncertainty in the current and the next period. A price reduction in the current period decreases x_t^* , but causes an increase in x_{t+1}^* . As indicated by Equation (2), such a price reduction lowers the exposure to risk in period t and raises the exposure in period $t + 1$. Alternatively, an increase in the current price increases the exposure to risk in period t and lowers the exposure in period $t + 1$. The owner optimally shifts risk exposure to that period in which there is more debt due, and thus the default probability is higher. The DLL effect is the effect of this dynamic risk-shifting on the firm's pricing policy. All else equal, it causes

¹¹ This effect is equivalent to the effect proposed by Dasgupta and Titman (1998). In their model, as in ours, if the firm defaults in the current period (period t), then the owner neither receives the benefit nor bears the cost of a lower current price. For this reason, only the $t + 1$ default probability appears in Equation (5). Chevalier and Scharfstein (1996) consider underinvestment in a model with costly state verification. Following a default, a firm is shut down but its owners keep the current profit. In this setting, a price cut is always costly, and the underinvestment effect therefore depends on the default probability in period t .

the owner to decrease (increase) the price if the current debt obligation will be higher (lower) in the next period than in the present period.

The DLL effect is similar to the limited-liability effects analyzed by Brander and Lewis (1986); Maksimovic (1986); and Showalter (1995). The effects identified in these papers follow from the idea that owners of limited-liability companies want to maximize their conditional expected payoffs across states in which their firms will not default, while disregarding the firms' profits in the default states. The DLL effect is similar in that it depends on the conditional expected values of the state variables $\tilde{\alpha}_t$ and $\tilde{\alpha}_{t+1}$ in the nondefault states of the periods t and $t + 1$. It differs from the limited-liability effects analyzed by Brander and Lewis (1986); Maksimovic (1986); and Showalter (1995) in that all of these papers present one-period models, whereas the DLL effect vanishes in a one-period version of our model.¹² In any multiperiod version of the model, however, the effect will exist in every period but the last one. The reason is that the DLL effect is an effect of the maturity structure of the firm's debt; it exists as long as the debt maturity structure is "nondegenerate," i.e., the firm has not yet reached its last period.

Our analysis extends the earlier analysis of Dasgupta and Titman (1998). Our model captures both the effect of an increase in the debt level (through the underinvestment effect) and the effect of a change in the debt maturity structure (through the DLL effect).¹³ The overall effect of debt on pricing depends on the interaction of these two effects. An increase in the current period debt due d_t affects the optimal current price only through the DLL effect; such an increase leads to a higher current price. An increase in the next period debt due d_{t+1} affects the current price through both the underinvestment and the DLL effects. Through the underinvestment effect, an increase in d_{t+1} leads to a higher current price. Through the DLL effect, an increase in d_{t+1} leads to a lower current price. The overall effect thus depends on the relative strength of the (positive) underinvestment effect and the (negative) DLL effect.¹⁴

¹² We thank a referee for pointing out that the DLL effect will not exist in a one-period version of our model. Showalter's model allows for a limited-liability effect on firms' pricing decisions even though his model has only one period. This difference between Showalter's model and ours is due to our assumption that the firm's profit is given by a multiplicatively separable function of price and uncertainty. Under this assumption, the firm's optimal pricing policy in a single-period model is chosen by setting the marginal profit from price changes equal to zero in each possible state. In contrast, Showalter's optimal price results from setting the firm's "average marginal profit equal to zero across all states of nature for which [the firm's equityholders] are residual claimants" (Showalter, 1995, p. 651). The way this average is defined depends on the way the state space is split into sets of default and nondefault states, because different states exhibit different marginal profits at the optimum. If instead, this marginal profit is set to zero in each state, then it is irrelevant how the state space is split into sets of default and nondefault states. As a result, there is no limited-liability effect in a one-period version of our model. In a multiperiod version there exists a (dynamic) limited-liability effect, because the marginal profit from price changes is *not* set to zero under the optimal pricing policy.

¹³ The DLL effect is not simply a combination of underinvestment effects, such as those analyzed by Chevalier and Scharfstein (1996) (for short-term debt) and Dasgupta and Titman (1998) (for long-term debt). These underinvestment effects depend on the probabilities with which a firm defaults at specific points in time, but not on the conditional expected values of the firm's state variables in the nondefault states. The DLL effect depends on the ratio of two such conditional expected values.

¹⁴ In any case, however, the effect of an increase in d_{t+1} is smaller than in a model without the DLL effect, such as that of Dasgupta and Titman (1996). Stomper and Zulehner (2004) proved that the underinvestment effect

3. The Empirical Evidence

3.1 The data

We test the theory using data on family-owned hotels that are located near ski resorts in Austria. This industry is ideal for testing the theory. Like the firm in our model, the hotels are owner-managed businesses that cater to repeat customers.¹⁵ Their sales depend on their accommodation quality, their prices and the snow conditions in the nearby ski resorts. Hotel owners typically set their prices in time to be published in travel agency prospectuses that appear in the Fall. This early price setting is necessary since many of the bookings for the ski season are made well before the season starts. The bookings are, however, typically cancelled if the snow conditions turn out to be bad. *Ex ante*, the cancellation rate is a random variable that corresponds to the multiplicative demand uncertainty in our model, with the extent of the uncertainty depending on uncertainty about snow conditions. We can thus use the altitude level of the nearby ski resorts as a proxy for a hotel's exposure to demand risk, with higher altitude corresponding to lower risk. Moreover, we can be reasonably certain that the hotels cannot predict future demand shocks since the snow conditions are notoriously hard to predict. Altogether, the demand uncertainty in this industry takes a form that is very similar to that in our model, and, as in the model, the uncertainty is resolved after the hotels set their prices.

Our empirical analysis reveals how the hotels' pricing decisions are related to their financial structures. As in the model, we treat firms' capital structures as exogenous. This assumption fits our sample well in that the hotels' owners appear to be quite constrained in their ability to optimize their firms' capital structures. Outside financing for the hotels is almost entirely debt financing. If the hotels receive equity financing, it is very rare that the financing comes from sources other than the hotels' current owners. The owners' financing capacity is, however, quite limited, and seems to be reserved for situations in which default is imminent. The hotels' financial structures are therefore mostly determined by the need to finance real investment and financing needs of the owner-families. For example, many hotels experience lasting leverage increases as a result of owners buying out family members or intrafamily real estate transactions. Such leverage changes happen regularly, e.g., when the ownership of a hotel is passed on to a younger generation.

Our theoretical model posits a specific relation between a firm's pricing decision in a given year and the firm's debt obligations due in that year and the

dominates the DLL effect in a two-period version of our model, in the sense that an increase in the next period debt due, with no other change, leads to an increase in the current price. It is not clear, however, that this proof will carry through to a model with more than two periods, where the value of ϵ_{t+1} is endogenously determined and depends on d_{t+1} .

¹⁵ Family-owned hotels are the norm in Austrian rural areas. Hotel chains specialize in city tourism and business travel. A recent survey by the Austrian National Tourist Office indicates that more than 40% of hotel guests are repeat visitors to the hotel.

following years. We implicitly assume that the firm's owner anticipates future changes in the firm's debt obligations that do not depend on the firm's pricing policy. Such changes occur, for example, due to the financing of construction projects, buy-outs of family members, etc. For our empirical analysis, we need only assume that any resulting debt changes are predictable one period ahead.

The firms' debt obligations are, however, also subject to some endogenous variation. The main reason for this variation is that a firm's pricing policy determines its exposure to demand uncertainty, and thus the extent of bank loans required to resolve liquidity problems in the wake of demand shocks. By treating the firms' debt obligations as predictable and exogenously given, we implicitly assume that their owners do not anticipate the possibility that future debt levels will depend on the current price. We adopt this assumption since we cannot measure the extent to which firms may require bank loans in order to resolve liquidity problems.¹⁶ Moreover, such bank loans would typically be small relative to the predictable exogenous financial structure changes mentioned above. We do, however, check that our qualitative results are not driven by a bias due to endogenous changes in the hotels' financial leverage.¹⁷

Our data provider is the Austrian Bank for Tourism, the "Österreichische Tourismus Bank" (ÖHT, "the bank"). The firms for which we have data are borrowers of the bank. All of the firms in the sample were incorporated as limited-liability companies and none were being dealt with by the restructuring department of the bank during the sample period.¹⁸ The full database includes complete information on 273 hotels and a total of 482 firm-years during the period 1999–2002: for 122 hotels, we have 1 year of data; for 96, we have 2 years; for 52 hotels 3 years; and for 3 hotels, we have 4 years of data. In order to include a firm-year in our regression analysis it is necessary that we have complete data on the following year for that firm. Thus, our empirical analysis is based on 209 firm-years (482 minus 273), representing data on 151 hotels (273 minus 122).

Descriptive statistics: In Table 1, we provide summary statistics for our data. The "used sample" of 209 observations, presented in the last three columns, is the data that we use in our regression analysis. We provide summary statistics on the "full sample" for comparison. In the full sample, we include not only

¹⁶ To do this estimation we would need data about the owners' wealth. Lacking such data, we assume that the hotels can resolve liquidity problems with cash injections from their owners. See Section 3.5 for a discussion of the validity of this assumption and related robustness checks.

¹⁷ We verify that operating and financial leverage have similar qualitative effects on the hotels' pricing decisions. See Section 3.5.

¹⁸ We exclude hotels that were dealt with by the restructuring department at the start of the sample period, since it is unclear whether they were owner-managed during the sample period. By excluding such hotels, we also exclude hotels involved in bankruptcy proceedings (because bankrupt firms would be dealt with by the restructuring department). Our sample does not include any hotels that defaulted during the sample period (in the sense of being referred to the restructuring department).

Table 1
Descriptive statistics

Variable	Description	Full sample		Used sample			
		Number of observations	Mean	Standard deviation	Number of observations	Mean	Standard deviation
Nature of business:							
$Cat_{i,t}$	Dummy for high quality hotels	603	0.55	0.50	209	0.60	0.49
$Cap_{i,t}$	Accommodation capacity (beds×days open for business)	603	48,541	46,680	209	47,772	42,650
$SBR_{i,t}$	Seat-to-bed ratio	560	2.18	2.07	209	2.02	1.48
$ISBR_{i,t} > 2$	Seat-to-bed dummy variable	603	0.55	0.50	209	0.54	0.50
Alt_i	Altitude of the closest meteorological station in meters	603	804	347	209	794	316
$I_{Alt_i > 1000}$	Altitude dummy variable	603	0.28	0.45	209	0.26	0.44
$Q_{i,t-1}$	Lagged number of overnight stays sold by hotel i and other hotels in the same resort	482	440,121	443,962	209	432,050	440,993
Operations:							
$q_{i,t}$	Number of overnight stays sold by hotel i	603	17,547	13,545	209	17,495	12,980
$p_{i,t}$	Price per night in Euros	603	83.73	54.01	209	79.43	45.66
$Mat_{i,t}$	Cost of materials in Euros	603	17.30	21.84	209	15.14	12.18
$Serv_{i,t}$	Cost of services in Euros	485	1.45	2.46	209	1.24	1.45
$k_{i,t}$	Total of fixed costs in Euros	590	820,489	826,975	209	818,798	787,083
$x_{i,t}$	Profits in Euros	485	1,100,107	1,137,344	209	1,062,521	1,008,629
Financial structure:							
$e_{i,t}$	Book value of equity in Euros	590	648,372	1,444,340	209	707,355	1,393,075
$d_{i,t}$	Short-term debt in Euros	590	1,233,073	1,386,578	209	1,225,725	1,534,072
	Total debt to total assets	598	0.86	0.19	209	0.85	0.18
	Short-term to long-term debt	590	0.99	0.37	209	1.00	0.34

This table reports descriptive statistics for family-owned hotels near Austrian ski resorts. The “used sample” is the data that is used in the regression analysis. Summary statistics are provided for the full sample for comparison. All of the data are for the years 1999–2002. The used sample comprises data for 151 hotels and 209 firm-years. $Cat_{i,t}$ is an indicator variable, which equals one if hotel i offers high-quality accommodation, rated four or five stars out of five. $Cap_{i,t}$ is the accommodation capacity of hotel i , defined as the product of the hotel’s number of beds, and the number of days the hotel is scheduled to stay open for business in the year t . $SBR_{i,t}$ is the ratio of seats in hotel i ’s restaurant to the number of beds in the hotel. $ISBR_{i,t} > 2$ is an indicator variable, which equals one if $SBR_{i,t} > 2$. Alt_i is the altitude of the meteorological station closest to hotel i . $I_{Alt_i > 1000}$ is an indicator variable, which equals one if $Alt_i > 1000$ meters. $Q_{i,t-1}$ is the total number of overnight stays that were sold in the year $t - 1$ by all hotels located in the same village as hotel i . $q_{i,t}$ is the number of overnight stays sold by hotel i during year t . $p_{i,t}$ is the average price that hotel i charged for one overnight stay. $Mat_{i,t}$ and $Serv_{i,t}$ are marginal costs, i.e., the cost of raw materials required for cooking and cleaning, and the labor cost of complimentary services that the hotel offers to its guests. $k_{i,t}$ denotes (quasi-)fixed costs of operation, defined as the sum of hotel i ’s wage bill, its costs of marketing, its administrative expenses, and the costs of energy and maintenance. $x_{i,t}$ is the profit of hotel i in year t , defined as $x_{i,t} = (p_{i,t} - c_{i,t})q_{i,t}$, where $c_{i,t} = Mat_{i,t} + Serv_{i,t}$. $e_{i,t}$ is the book value of the equity of hotel i in the year t . $d_{i,t}$ is the book value of the hotel’s debt that is due to be repaid in year t . We also report summary statistics on the ratio of the book value of a hotel’s debt to the value of its total assets and the ratio of the book values of the short-term and the long-term debt, where the latter is defined as debt that is due to be repaid after 1 year.

the 482 firm-years for which we have complete data, but also an additional 121 firm-years for which we have only partial data. All Euro-denominated variables have been adjusted for inflation and are expressed as 1999 Euro values.

The first seven variables describe the nature of a hotel's business and its market. Cat_i is a dummy variable that equals one if hotel i has a four or five star rating (out of five), and zero otherwise. This variable proxies for the hotels' accommodation quality. $Cap_{i,t}$ is hotel i 's accommodation capacity, defined as the product of the hotel's number of beds and the number of days the hotel plans to stay open for business in year t .¹⁹ $SB R_{i,t}$ denotes the ratio of seats in hotel i 's restaurant to the number of its beds. This ratio proxies for the degree to which the profit of a hotel depends not only on its room sales, but also on the profitability of the hotel restaurant. Hotels with relatively sizeable restaurants are further distinguished from other hotels by means of an indicator variable: $I_{SB R_{i,t} > 2}$ equals one if $SB R_{i,t}$ is greater than two, and zero otherwise.

A hotel's market is characterized by the following variables. Alt_i is the altitude of the meteorological station that is closest to hotel i . This variable proxies for the altitude of ski resorts in the proximity of the hotel since the meteorological stations are usually located close to the base terminals of ski resorts. $I_{Alt_i > 1000}$ is a dummy variable that equals one if Alt_i is at least 1000 meters, and zero otherwise. If $I_{Alt_i > 1000} = 1$, then the hotel is located in an area where the snow conditions are more likely to be good. $Q_{i,t-1}$ is the total number of overnight stays sold by hotel i and all of the other hotels in the same village as hotel i , during the year prior to year t .²⁰

The next six variables describe the hotels' operations. $q_{i,t}$ is the number of overnight stays sold by hotel i in year t . $p_{i,t}$ is the average price that the hotel charged for one overnight stay, where the average is taken across all overnight stays sold in the year t . This price contains markups on two marginal costs, $Mat_{i,t}$ and $Serv_{i,t}$. $Mat_{i,t}$ is the total annual cost of raw materials required for cooking and cleaning, divided by $q_{i,t}$. $Serv_{i,t}$ is the total annual cost for all services that are included in the cost of the room (e.g., cleaning, breakfast preparation, etc.), divided by $q_{i,t}$. In addition, the hotels incur fixed costs, denoted as $k_{i,t}$ and defined as the sum of wages, costs of marketing, administrative expenses, as well as costs of energy and maintenance.²¹ These fixed costs are not considered when we compute the hotels' profits, denoted as $x_{i,t}$. Instead, this profit is defined as the product of the number of overnight stays sold, $q_{i,t}$, and the markup $p_{i,t} - (Mat_{i,t} + Serv_{i,t})$. The fixed costs $k_{i,t}$ are treated as part of the current liabilities that must be paid in order for hotel i to remain solvent in year t . Our empirical analysis therefore not only reveals how the hotels'

¹⁹ The hotel's operation schedule depends on the scheduled opening and closing dates of nearby ski resorts. Hotels report their scheduled opening and closing dates to the bank.

²⁰ Overnight stays are per person, not per room.

²¹ $k_{i,t}$ does not include the variable labor costs that are accounted for by the variable $Serv_{i,t}$.

prices depend on their financial leverage, but also how the prices depend on the hotels' operating leverage due to fixed costs of operation.

At the bottom of Table 1, we present descriptive statistics concerning the hotels' capital structures. We report the mean and the standard deviation of the book values of the hotels' equity and their short-term debt, i.e., debt with a statutory term to maturity less than 1 year. In addition, we report the mean and the standard deviation of the hotels' overall leverage, defined as the ratio of the book value of a hotel's debt (long-term plus short-term) to its total assets. The hotels are highly levered, with an average leverage of 85%.²² Finally, we report the ratio of the book values of a hotel's short-term and long-term debt. We find that the average of this ratio is approximately one. It is, however, quite common that the hotels roll over a large part of their short-term debt.

3.2 The hypotheses

Equation (5) of Section 2 summarizes our theory. To obtain testable hypotheses, we rearrange the equation and substitute in the expressions for various derivatives, as described in the Appendix. We thus obtain the following pricing policy function that is the theoretical foundation of our empirical analysis:

$$p_t = c_t - \frac{q_t^*}{dq_t^*/dp_t} + \beta \lambda \frac{q_{t+1}^*}{dq_{t+1}^*/dp_{t+1}} (1 - F[\underline{\alpha}_{t+1}]) (1 + tDLL_t), \quad (11)$$

$$\text{where } tDLL_t = 1/DLL_t - 1. \quad (12)$$

As discussed in Section 2, we assume that each firm's customer base, $q_{i,t}^*$, is a deterministic function of the previous year's customer base, $q_{i,t-1}^*$, and the current price, $p_{i,t}$: $q_{i,t}^* = \lambda q_{i,t-1}^* + n^*[p_{i,t}]$, where the function $n^*[p_{i,t}]$ captures the demand of new customers. By further assuming that $n^*[p_{i,t}]$ is a linear function, $n^*[p_{i,t}] = a - b p_{i,t}$, we obtain the following stylized regression model:

$$\begin{aligned} p_{i,t} = & \gamma_0 + \gamma_1 c_{i,t} + \gamma_2 q_{i,t}^* \\ & + \gamma_U q_{i,t+1}^* (1 - F_i[\underline{\alpha}_{i,t+1}]) \\ & + \gamma_D q_{i,t+1}^* (1 - F_i[\underline{\alpha}_{i,t+1}]) tDLL_{i,t} \\ & + \dots + \xi_{i,t}, \end{aligned} \quad (13)$$

where $\xi_{i,t}$ is an error term and $\gamma_U = \gamma_D = -\beta\lambda/b < 0$ since $dq_{i,t+1}^*/dp_{i,t+1} = -b$.

The regression model (13) contains the following endogenous variables: (i) firm i 's customer base in the periods t and $t+1$, $q_{i,t}^*$ and $q_{i,t+1}^*$, (ii) the default probability $F_i[\underline{\alpha}_{i,t+1}]$, and (iii) the variable $tDLL_{i,t}$. In the next section, we describe the first-stage estimates that we use to construct exogenous proxies for these variables. These proxies replace the above-stated variables in our

²² The hotels' average leverage is somewhat above that of other small and medium-sized enterprises in Austria. Dirschnid and Waschiczek (2005) report an average leverage of 81% for Austrian firms with sales below 7 million Euros.

second-stage regressions. Moreover, we extend the regression (13) by adding four explanatory variables. Two of these variables replace the marginal cost $c_{i,t}$. We distinguish between two kinds of marginal costs denoted by $Mat_{i,t}$ and $Serv_{i,t}$, and defined as the cost of “raw materials” required for cooking, cleaning, etc., and the labor cost of services that are included in an overnight stay. The other two variables are Cat_i and $\ln[Alt_i/1000]$. These variables are included in our regression in order to control for effects of a hotel’s quality and its location on its price. We thus obtain the following specification:

$$\begin{aligned}
 p_{i,t} = & \gamma_0 + \gamma_{1M}Mat_{i,t} + \gamma_{1S}Serv_{i,t} + \gamma_2\hat{q}_{i,t} \\
 & + \gamma_U\hat{q}_{i,t+1}(1 - \hat{G}_{i,t+1}) \\
 & + \gamma_D\hat{q}_{i,t+1}(1 - \hat{G}_{i,t+1})t\hat{DLL}_{i,t} \\
 & + \gamma_3\ln[Alt_i/1000] + \gamma_4Cat_i + \xi_{i,t},
 \end{aligned} \tag{14}$$

where any variable with a hat denotes an exogenous proxy for an endogenous explanatory variable of the regression (13) and appears in the place of the latter variable.

We conclude this section by stating our hypotheses. These hypotheses are alternatives to the null hypothesis that leverage does not affect firms’ pricing decisions, i.e., that $\gamma_U = \gamma_D = 0$.

Testing the underinvestment effect: We first test the theory of Dasgupta and Titman (1998): a levered firm underinvests in its customer base because it values future profits using an effective discount factor equal to β times the nondefault probability, $(1 - F_i[\alpha_{i,t+1}])$. This theory yields the following hypothesis:

H_U: In regression (14), with the constraint that $\gamma_D = 0$, $\gamma_U < 0$.

Testing the DLL effect: We test the dynamic limited-liability effect by testing the *incremental* explanatory power of the variable $tDLL_{i,t}$ in regression (13). We therefore estimate this regression without the constraint that $\gamma_D = 0$, and test the following hypothesis:

H_{UD}: In regression (14), $\gamma_D = \gamma_U < 0$.

3.3 First-stage estimates

This section describes the first-stage estimates that we use in order to construct proxies for the endogenous explanatory variables of regression (13): (i) firm i ’s customer base in the periods t and $t + 1$, $q_{i,t}^*$ and $q_{i,t+1}^*$, (ii) the default probability $F_i[\alpha_{i,t+1}]$, and (iii) the variable $tDLL_{i,t}$.

Proxies for the current and future customer base, $q_{i,t}^*$ and $q_{i,t+1}^*$: We use the firms’ sales as a proxy for their customer bases. As discussed in Section 3.1, the sales of hotel i in a given year t , $q_{i,t}$, are defined as the number of overnight stays sold in that year. Since this number depends on the price $p_{i,t}$,

we require an instrument. The instrument is constructed by means of a first-stage regression, based on three instrumental variables. The first variable is hotel i 's accommodation capacity $Cap_{i,t}$, defined as the product of the number of beds in the hotel times the number of days it plans to stay open in the year t . Both of these factors are exogenously determined.²³ The second instrumental variable is $Q_{i,t-1}$, the total number of overnight stays sold by hotel i and all of the other hotels in the same village as hotel i , during the year prior to year t . This variable captures changes in the size of a hotel's market as a proxy for the extent to which the hotel is booked by repeat customers.²⁴ Finally, we use regional fixed effects in order to capture the notion that the hotels' sales depend on their locations. These fixed effects are based on the first three digits of the hotels' four-digit postal codes.

We denote the instruments for hotel i 's sales in the periods t and $t + 1$ as $\hat{q}_{i,t}$ and $\hat{q}_{i,t+1}$, respectively. These instruments are substituted for $q_{i,t}^*$ and $q_{i,t+1}^*$ in the regression model (13).

Proxies for the default probability $F_i[\underline{\alpha}_{i,t}]$: In our theoretical analysis, the default probability $F_i[\underline{\alpha}_{i,t}]$ is defined as the probability with which a firm's profit falls sufficiently short of the minimum required for debt repayment that the firm's owners allow the firm to default. In the empirical analysis, we take into account the fact that a firm's default risk depends not only on its financial leverage but also on its operating leverage. The firms' current financial obligations include both the debt that is due in period t , $d_{i,t}$, and the fixed costs, $k_{i,t}$. The default trigger $\underline{\alpha}_{i,t}$ is thus now defined by the following extension of condition (3):

$$d_{i,t} + k_{i,t} - \underline{\alpha}_{i,t} x_i^*[p_{i,t}, q_{i,t-1}^*] = \beta V_{i,t+1}. \quad (15)$$

For any given value of $\underline{\alpha}_{i,t}$, we can calculate the default probability $F_i[\underline{\alpha}_{i,t}]$ if we know the distribution of the state variable $\tilde{\alpha}_{i,t}$. This variable is not directly observed, but we do observe the hotels' profits and we can define the default trigger in terms of profit: $\underline{x}_{i,t} = \underline{\alpha}_{i,t} x_i^*[p_{i,t}, q_{i,t-1}^*]$. The default probability $F_i[\underline{\alpha}_{i,t}]$ is thus measured as the probability $G_{i,t}[\underline{x}_{i,t}]$ with which hotel i 's period t profit falls short of $\underline{x}_{i,t}$, where

$$\underline{x}_{i,t} = d_{i,t} + k_{i,t} - \beta V_{i,t+1}. \quad (16)$$

²³ The number of beds of a typical hotel is exogenously determined by the size of its building. Many hotels operate on the premises of former farms that were converted into hotels without major reconstruction (in order to keep the original look of the buildings). Moreover, avalanche danger and building codes restrict the construction of new facilities. The hotels' scheduled opening and closing dates are determined by those of the nearby ski resorts.

²⁴ The variable $Q_{i,t-1}$ is somewhat endogenous since it depends on hotel i 's sales in period $t - 1$. However, most of the hotels in our sample are located in villages that are major tourist destinations and that have a large number of hotels. As a consequence, a single hotel accounts only for a small fraction of the aggregate sales of all hotels in the village.

In order to calculate a proxy for the default trigger $\underline{x}_{i,t}$, we use the book value of hotel i 's equity in period t as a proxy for the discounted future equity value, $\beta V_{i,t+1}$.²⁵ The fixed costs $k_{i,t}$ are defined as described in Section 3.1. The current debt $d_{i,t}$ is the debt that must be repaid in order to avoid defaulting in the current year. The value of $d_{i,t}$ depends on the extent to which firms can roll over short-term debt, i.e., debt with a statutory maturity date in the current year. We have found that typically the firms in our dataset pay in any given year about 10% of what is reported as short-term debt in the firms' accounting statements. We thus define the current debt $d_{i,t}$ as 10% of the short-term debt in hotel i 's balance sheet in period t .²⁶ The proxy for the default trigger $\underline{x}_{i,t}$ is denoted as $\hat{x}_{i,t}$.

The proxy for the period $t + 1$ default trigger $\hat{x}_{i,t+1}$ is constructed in a manner that is similar to that for period t . We, however, instrument the period $t + 1$ equity value $\beta V_{i,t+2}$ using the same instrument as for $\beta V_{i,t+1}$, i.e., the current (period t) book value of equity; the period $t + 1$ book value of equity cannot be used since this value is likely to be endogenously determined.²⁷ As a consequence, any difference between the default triggers $\hat{x}_{i,t}$ and $\hat{x}_{i,t+1}$ is due to differences in the fixed costs and the debt due in the periods t and $t + 1$. We do not use an instrument for the future debt level $d_{i,t+1}$ since we want to ensure that our estimates capture the effects of changes in debt levels that are caused by predictable exogenous events. We therefore calculate the period $t + 1$ debt due exactly as was done above for the period t debt due, except that we use the short-term debt reported in the period $t + 1$ balance sheet. We thus treat the equity value as the only endogenous component of the default trigger $\underline{x}_{i,t+1}$.

Our estimates of the default probability $G_{i,t}[\underline{x}_{i,t}]$ are based on the assumption that the hotels' profits are lognormally distributed.²⁸ Exogenous proxies for the distribution parameters are obtained by means of the following first-stage regression:

$$\ln[x_{i,t}] = \kappa_0 + \kappa_1 \ln[Cap_{i,t}] + \kappa_2 Cat_i + \kappa_3 \ln[Alt_i/1000] + \dots + \zeta_{i,t}, \quad (17)$$

where $Cap_{i,t}$ is hotel i 's accommodation capacity, Cat_i is a dummy variable that equals one if hotel i is high quality, and Alt_i is the altitude of the closest meteorological station (a proxy for the altitude of nearby ski resorts). In addition, we also include the exogenous explanatory variables of the second-stage regression.

²⁵ The year t book value of a hotel's equity does not depend on the hotel's current price, p_t , since the hotels submit their accounting statements before the start of the skiing season.

²⁶ Below, in Section 3.5 on robustness checks, we repeat our empirical analysis using different assumptions regarding what must be paid.

²⁷ We can use the period t book value of equity as a proxy for both $\beta V_{i,t+1}$ and $\beta V_{i,t+2}$ since all of our data has been adjusted for inflation. In a robustness check, we set $\beta V_{i,t+1} = \beta V_{i,t+2} = 0$.

²⁸ A Shapiro-Wilk test shows that this assumption is consistent with the profit distribution for the firms in our sample. Negative profits don't occur since fixed costs are not included in the definition of the profit $\bar{x}_{i,t}$.

As a result of running regression (17), we obtain point estimates of the coefficient vector $\vec{\kappa}$, as well as a variance-covariance matrix of these estimates. These regression outputs define a multivariate normal distribution from which we draw coefficient vectors. For each draw j , we calculate estimates of the mean and variance of the distribution of the logarithmic profit for each hotel i . This estimated pair is denoted as: $(\hat{\mu}_{i,t}^j, \hat{\sigma}^j)$, where $\hat{\mu}_{i,t}^j$ denotes a predicted value for $\ln[x_{i,t}]$ and $\hat{\sigma}^j$ is the prediction error variance across all firm-years.²⁹ Using this pair, we can calculate the probability of a profit outcome less than $\hat{x}_{i,t}$, which is the proxy for the default trigger, thus obtaining an estimate of the default probability $G_{i,t}[x_{i,t}]$. Since this computation requires a nonlinear transformation of the underlying estimates $(\hat{\mu}_{i,t}^j, \hat{\sigma}^j)$ any errors in these estimates will bias any single estimate of $G_{i,t}[x_{i,t}]$, even if the mean of the errors is equal to zero. We, therefore, repeat the sampling procedure 1000 times and calculate the following estimate of $G_{i,t}[x_{i,t}]$ that is approximately unbiased and exogenous with respect to the price $p_{i,t}$:

$$\hat{G}_{i,t} = \frac{1}{1000} \sum_{j=1}^{1000} \Phi \left[\frac{\ln[\hat{x}_{i,t}] - \hat{\mu}_{i,t}^j}{\hat{\sigma}^j} \right], \quad (18)$$

where Φ denotes the standard Normal distribution function.

Proxies for the variable $tDLL_{i,t}$: In the Appendix, we redefine the variable $tDLL_{i,t}$ in terms of profits in order to obtain:

$$tDLL_{i,t} = \frac{\frac{E[\tilde{x}_{i,t+1}|x_{i,t+1} \geq \hat{x}_{i,t+1}]}{E[\tilde{x}_{i,t+1}]} - \frac{E[\tilde{x}_{i,t}|x_{i,t} \geq \hat{x}_{i,t}]}{E[\tilde{x}_{i,t}]}}{\frac{E[\tilde{x}_{i,t}|x_{i,t} \geq \hat{x}_{i,t}]}{E[\tilde{x}_{i,t}]}}. \quad (19)$$

Expression (19) shows that the variable $tDLL_{i,t}$ depends on ratios between a hotel's conditional expected profit, given that the hotel does not default in a certain period, and its unconditional expected profit for the same period. Assuming that the hotels' profits are lognormally distributed, we can estimate these profit ratios using the first-stage regression (17) and the proxies $\hat{x}_{i,t}$ and $\hat{x}_{i,t+1}$ for the default triggers. Using the fact that, for a lognormally distributed variable, $\tilde{z}$, $E[\tilde{z}|z \geq a] = E[\tilde{z}]\Phi[(\mu - \ln[a])/\sigma + \sigma]/(1 - \Phi[(\ln[a] - \mu)/\sigma])$, we can write:

$$\frac{E[\tilde{x}_{i,t}|x_{i,t} \geq \hat{x}_{i,t}]}{E[\tilde{x}_{i,t}]} \approx \frac{\Phi \left[\frac{\hat{\mu}_{i,t}^j - \ln[\hat{x}_{i,t}]}{\hat{\sigma}^j} + \hat{\sigma}^j \right]}{1 - \Phi \left[\frac{\ln[\hat{x}_{i,t}] - \hat{\mu}_{i,t}^j}{\hat{\sigma}^j} \right]}. \quad (20)$$

²⁹ Only $\hat{\mu}_{i,t}^j$ varies across firms and years. The same value of $\hat{\sigma}^j$ is used as a proxy for the profit uncertainty for all firm years. We thus seek to mitigate the problem that the residuals of the first-stage regression are not exogenous. The residual for a single firm year has a negligible effect on the value of $\hat{\sigma}^j$.

In order to avoid a bias due to estimation errors, we follow the same procedure as in constructing our proxy for the default probability $G_{i,t}[x_{i,t}]$. We draw 1000 estimates $(\hat{\mu}_{i,t}^j, \hat{\mu}_{i,t+1}^j, \hat{\sigma}^j)$ and compute 1000 estimates of $tDLL_{i,t}$ as outlined above. The average of these estimates is our proxy for the variable $tDLL_{i,t}$, denoted by $t\hat{DLL}_{i,t}$.

Identification: We exclude from the second-stage regressions the following variables: the instrumental variables for the firms' sales, the firms' fixed costs in the periods t and $t + 1$, $k_{i,t}$, and $k_{i,t+1}$, and their financial obligations in these periods, $d_{i,t}$ and $d_{i,t+1}$. The last two exclusion restrictions are required in order to identify the underinvestment effect and the DLL effect.³⁰ The identifying instruments for the firms' sales are the lagged village-level sales, $Q_{i,t-1}$, and the regional fixed effects.

First-stage estimates: We run the first-stage regression (17) using two different specifications. We first perform a simple ordinary least squares (OLS) estimation. The OLS estimates are, however, prone to estimation errors due to heteroscedasticity, which may bias our proxies for the underinvestment effect and the DLL effect (as discussed above). We, therefore, also estimate the regression (17) with random effects:

$$\zeta_{i,t} = v_i + u_{i,t}, \quad (21)$$

where v_i denotes the random effect for hotel i . We refine the estimation further by allowing the variance of the residuals $u_{i,t}$ to vary across four groups of hotels that are likely to differ in their exposure to profit uncertainty. These four groups are defined by the dummy variables $I_{Alt_i > 1000}$ and $I_{SBR_i > 2}$ indicating hotels in areas more or less suited for ski tourism, and hotels with relatively large or small restaurants, respectively. Each hotel is assigned to the group of hotels with the same combination of values of $I_{Alt_i > 1000}$ and $I_{SBR_i > 2}$, and separate estimates of the standard deviation σ_u are computed for each group. 89 firm-years fall into the category small restaurant and low altitude; 65 are in the category large restaurant and low altitude; 27 are in the category small restaurant and high altitude; 28 are in the category large restaurant and high altitude.

Table 2 presents the estimates for the first-stage regression (17). The estimates in column (1) were obtained by means of OLS for the pooled sample. Column (2) presents the random-effects estimates. We do find evidence of heteroscedasticity. Column (2) states that the point estimate of the standard deviation of the random effects is $\hat{\sigma}_v = 0.464$, and a Breusch-Pagan test shows

³⁰ Identification is possible even though both effects depend on the variables $k_{i,t+1}$ and $d_{i,t+1}$. These variables are transformed in different nonlinear ways when we compute our proxies for the underinvestment effect and the dynamic limited liability effect. Moreover, our proxy for the underinvestment effect, $\hat{G}_{i,t+1}$, does not depend on the variables $k_{i,t}$ and $d_{i,t}$ that are used in computing the proxy for the DLL effect.

Table 2
First-stage estimates

Dependent variable: $\ln[\text{profit } x_{i,t}]$				
Variable	Description	Coefficient	(1) OLS	(2) RE
<i>Constant</i>	Constant	β_0	3.549 (2.57)*	6.16 (4.29)**
$\ln[Cap_{i,t}]$	$\ln[\text{Capacity}=\text{beds} \times \text{days open for business}]$	β_1	0.616 (7.12)**	0.433 (4.99)**
$Mat_{i,t}$	Cost of materials	β_2	0.012 (2.43)**	0.002 (0.46)
$Serv_{i,t}$	Cost of services	β_3	0.020 (0.48)	-0.009 (0.27)
Cat_i	Dummy for high quality hotels	β_4	0.702 (5.92)**	0.781 (5.69)**
$\ln[Alt_i/1000]$	$\ln[\text{Altitude of closest meteorological station}]$	β_5	0.486 (3.54)**	0.363 (2.40)**
$\hat{\sigma}_\xi$	Standard deviation of OLS-residuals		0.738	
$\hat{\sigma}_v$	Standard deviation of random effects			0.464
$\hat{\sigma}_u$	Standard deviation of residuals if $I_{SBR_{i,t}>2} = 0$ and $I_{Alt_i>1000} = 0$			0.518
$\hat{\sigma}_u$	Standard deviation of residuals if $I_{SBR_{i,t}>2} = 1$ and $I_{Alt_i>1000} = 0$			0.065
$\hat{\sigma}_u$	Standard deviation of residuals if $I_{SBR_{i,t}>2} = 0$ and $I_{Alt_i>1000} = 1$			0.105
$\hat{\sigma}_u$	Standard deviation of residuals if $I_{SBR_{i,t}>2} = 1$ and $I_{Alt_i>1000} = 1$			0.097
<i>R</i> -squared			0.38	
Log-Likelihood				-174.786
Number of firm-years			209	209
Number of firms			151	151

This table reports first-stage estimation results for the relation between hotels' profits and exogenous variables, based on a sample of 151 Austrian hotels and 209 firm-years during the period 1999–2002. Profits are assumed to be lognormally distributed. $\ln[Cap_{i,t}]$ denotes the log of the accommodation capacity of hotel i in the year t , defined as the product of the hotel's number of beds, and the number of days the hotel is scheduled to stay open for business. $Mat_{i,t}$ and $Serv_{i,t}$ are marginal costs, i.e., the cost of raw material required for cooking and cleaning, and the labor cost of complimentary services that hotel i offers to its guests. Cat_i is an indicator variable, which equals one if hotel i offers high-quality accommodation, rated four or five stars out of five. $\ln[Alt_i/1000]$ denotes the logarithm of the altitude of the meteorological station closest to hotel i , which serves as a proxy for the altitude of ski resorts in the proximity of the hotel. Column (1) presents OLS estimates, based on the pooled sample. Column (2) presents random-effects (RE) estimates, with firm-specific random effects, v_i , and residuals denoted as $u_{i,t}$. Separate estimates of the standard deviation of the residuals are reported for four different groups of hotels. Each group is characterized by a specific combination of values of the dummy variables $I_{Alt_i>1000}$ and $I_{SBR_{i,t}>2}$ that indicate hotels in regions especially suited for ski tourism, and hotels with relatively sizable restaurants, respectively. t - and z -statistics are stated in parentheses; **(*) indicates significant coefficients, at a 95% (90%) level of significance.

that this estimate is significantly different from zero. Moreover, the standard deviation of the OLS residuals, $\hat{\sigma}_\xi = 0.738$ is substantially higher than the residual variance estimates in column (2). In column (2) it is also shown that $\hat{\sigma}_u$ varies cross-sectionally. These results are consistent with our knowledge of the industry. An estimate of $\hat{\sigma}_u = 0.518$ is found for hotels located close to relatively low-altitude ski-resorts ($Alt_i \leq 1000$) and with relatively small

restaurants ($SB R_{i,t} \leq 2$). This estimate is significantly higher than that for any other group of hotels. This result is intuitively appealing since the hotels in the former group are more exposed to demand uncertainty than hotels close to ski resorts at high levels of altitude, and are less diversified than hotels with big restaurants.

For the remainder of our analysis, we use the results of the random effects regression that are presented in column (2) of Table 2.³¹ We follow the procedures outlined above in order to construct proxies for the default probability $G_{i,t+1}[\underline{x}_{i,t+1}]$ and the variable $tDLL_{i,t}$. In constructing these proxies, we take into account that the firm-specific effects v_i pick up endogenous variation in the hotels' profits. We thus set these effects to zero when we estimate the means of the hotels' logarithmic profits, $\hat{\mu}_{i,t}^j$. The estimates for σ_u are used as measures of profit uncertainty due to time-varying demand, and are substituted for $\hat{\sigma}^j$ in expression (18). We then use Equation (18) to calculate a proxy, $\hat{G}_{i,t+1}$, for the default probability. Similarly, by substituting estimates $\hat{\mu}_{i,t}^j$, $\hat{\mu}_{i,t+1}^j$ and $\hat{\sigma}^j$ into Equations (20) and (19), we obtain a proxy for the variable $tDLL_{i,t}$ that we denote as $t\hat{DLL}_{i,t}$.

In Table 3, we report the distributions of five alternative proxies for the default probability, $G_{i,t+1}[\underline{x}_{i,t+1}]$, (Panel A), and the variable $tDLL_{i,t}$ (Panel B). The five columns of Table 3 differ in the assumptions that we make regarding the amount of short-term debt that must be paid and the amount of capital that owners will inject into the hotels in order to avoid default. These assumptions determine the values that we assign to the variables $d_{i,t}$ and $\beta V_{i,t+1}$ in Equation (16). Column (2) presents the base-case estimates, i.e., the variables $\hat{G}_{i,t+1}$ and $t\hat{DLL}_{i,t}$ that are used in our second-stage regressions. As discussed above, we assume that in order to avoid default firms must pay 10% of their nominal short-term debt, and firm owners are willing and able to inject new equity capital up to an amount equal to the current book equity value. Thus, in Column (2), we set $d_{i,t}$ equal to 10% of the current debt and $\beta V_{i,t+1}$ equal to the current book value of the equity.

The estimates in columns (1) and (3)-(5) of Table 3 are used to run robustness checks, described below in Section 3.5. In columns (1) and (3), we continue to set $\beta V_{i,t+1}$ equal to the current book value of equity, but in column (1), we assume that firms must repay all of their short-term debt ($d_{i,t} = 100\%$ of short-term debt), and in column (3), we assume that all short-term debt is rolled over ($d_{i,t} = 0$). In columns (4) and (5), we assume that firm owners will not inject any new equity capital into the firm ($V_{i,t+1} = 0$). In column (4), we set $d_{i,t} = 10\%$ of short-term debt and in column (5), we set $d_{i,t} = 0$. In all columns it is assumed that the firms must pay their fixed costs, $k_{i,t}$, in full.

The estimates in Panel B of Table 3 reveal the direction of the DLL effect for the firms in our sample. As discussed in Section 2, this effect can either

³¹ Our qualitative results are robust to using the OLS estimates, as was demonstrated in a previous version of the present paper, Stomper and Zulehner (2004).

Table 3
Distributions of proxies for the central explanatory variables

Panel A: Proxies for the default probability $G_{i,t+1}[\underline{x}_{i,t+1}]$					
% Of nominal short-term that must be paid:	100%	10%	0%	10%	0%
Maximum capital input, as % of book equity:	100%	100%	100%	0%	0%
Percentiles	(1)	(2)	(3)	(4)	(5)
90%	0.998	0.841	0.814	0.993	0.988
75%	0.790	0.248	0.161	0.859	0.804
50%	0.099	0.000	0.000	0.215	0.192
25%	0.000	0.000	0.000	0.002	0.001
10%	0.000	0.000	0.000	0.000	0.000
Further descriptive statistics					
Mean	0.342	0.197	0.182	0.393	0.373
Standard deviation	0.403	0.330	0.318	0.399	0.394
Number of observations (firm-years)	209	209	209	209	209

Panel B: Proxies for the variable $tDLL_{i,t}$					
Percentiles	(1)	(2)	(3)	(4)	(5)
10%	-0.254	-0.055	-0.041	-0.037	-0.042
25%	-0.005	0.000	0.000	-0.001	-0.001
50%	0.000	0.000	0.000	0.000	0.000
75%	0.056	0.046	0.041	0.027	0.024
90%	0.791	0.216	0.206	0.134	0.097
Further descriptive statistics					
Mean	0.091	0.051	0.047	0.052	0.047
Standard deviation	0.359	0.210	0.196	0.191	0.184
Number of observations (firm-years)	209	209	209	209	209

This table characterizes the distributions of two proxies for two different effects of leverage on hotels' pricing strategies. The sample includes 151 Austrian hotels and 209 firm-years during the period 1999–2002.

Panel A reports descriptive statistics for estimates of the probability with which the firms default in any given year. We report the distributions of five proxies for the default probability $G_{i,t+1}[\underline{x}_{i,t+1}]$, which follow from the first-stage estimates reported in column (2) of Table 2. These estimates are based on different assumptions about firms' ability to roll over short-term debt, and their access to equity financing through their owners. In the first three columns, we assume that the firm's owners stand ready to provide the firms with fresh capital up to an amount equal to the firm's current equity value. In column (1), we assume that the firms have to repay 100% of their short-term debt. In column (2), we assume that the firms have to repay 10% of their short-term debt, and they can roll over the rest. In column (3), we assume that the firms can roll over their entire short-term debt. In columns (4) and (5), we assume that the firms cannot obtain capital injections from their owners, and that they have to pay 10% of their short-term debt (column (4)) or none of this debt (column (5)). **Panel B** reports descriptive statistics for estimates of the variable $tDLL_{i,t}$, defined in expression (12). We report the distributions of five proxies for $tDLL_{i,t}$, which follow from the first-stage estimates reported in column (2) of Table 2. The estimates in each column are based on the same assumptions as the estimates stated in the same column in Panel A.

ameliorate or exacerbate the underinvestment effect of Dasgupta and Titman (1998). If $tDLL_{i,t} > 1$, then the underinvestment effect is exacerbated: the DLL effect induces firm i to set a higher price, and, thus, to invest less in its customer base. Since $tDLL_{i,t} = 1/DLL_{i,t} - 1$, this case is characterized by values of $tDLL_{i,t} < 0$. For most firms in our sample, however, the variable $tDLL_{i,t}$ takes positive values. Thus, in our sample, the DLL effect typically ameliorates the underinvestment effect and decreases the extent to which firms underinvest in extending their customer bases.

In addition to the results discussed above, we also compute first-stage estimates for the hotels' room sales. These estimates are not interesting in their

own right, and are thus omitted. We, however, want to point out that we obtain “strong” instruments for $q_{i,t}$ and $q_{i,t+1}$ (in the terminology of Staiger and Stock, 1997).³²

3.4 Second-stage estimates

Table 4 reports the correlations of all variables that appear in (14).³³ There are no problems of multicollinearity. The price $p_{i,t}$ is negatively correlated with the variable $(1 - \hat{G}_{i,t+1})$ that serves as a proxy for the underinvestment effect. This negative correlation is consistent with the predictions of Dasgupta and Titman (1998) as stated in the hypothesis $\mathbf{H}_U$.

Table 5 reports random-effects estimates for the regression (14) with z -statistics based on standard errors that are adjusted for use under two-stage-least-squares estimation. The estimates in column (1) are for a benchmark model in which γ_U and γ_D are constrained to be zero. Column (2) presents the estimates for Equation (14), with the constraint that $\gamma_D = 0$. Column (3) presents the estimates for Equation (14), without this constraint.

All of the columns show that the hotels’ prices depend significantly on their marginal costs, $Mat_{i,t}$ and $Serv_{i,t}$. In column (1), we obtain a significantly negative estimate of the coefficient γ_2 for the hotels’ current sales, consistent with the existence of economies of scale, and/or the existence of local market power. In columns (2) and (3) the estimates of this coefficient are also negative, but not significant. In all columns, the hotels’ prices are significantly positively related to the altitude of nearby ski resorts and accommodation quality: the coefficients of the variables $I_{Alt_i > 1000}$ and Cat_i are positive and significantly different from zero. The benchmark model in column (1) explains the hotels’ prices with an R^2 of 63%; this R^2 is in line with the explanatory power of similar models in the related literature, e.g., Phillips (1995).

In both columns (2) and (3), we obtain negative estimates of the coefficient γ_U , consistent with the hypothesis $\mathbf{H}_U$. The estimate is, however, significantly negative only in column (3). It is thus in our full model, column (3), that we find evidence of the underinvestment effect. The evidence indicates that hotels’ prices are decreasing in the probability that they will remain solvent in the next period. This result corresponds to the predictions of Dasgupta and Titman (1998). The lack of a significant coefficient estimate in column (2) may be the consequence of an omitted-variables bias, resulting from setting $\gamma_D = 0$, thus ignoring the DLL effect.

In column (3) of Table 5, we remove the constraint that $\gamma_D = 0$, in order to test the hypothesis $\mathbf{H}_{UD}$. The estimate of the coefficient γ_D is significantly negative. Moreover, the P -value at the bottom of Table 5 shows that we cannot reject the hypothesis that $\gamma_D = \gamma_U$. We thus obtain evidence consistent with

³² The first-stage regression explains hotels’ room sales with an R^2 of 84% and an F-value of 103.71.

³³ We only include $\hat{q}_{i,t}$, not $\hat{q}_{i,t+1}$, in Table 4. These two variables are highly correlated with each other. This correlation does not pose a problem for us since $\hat{q}_{i,t+1}$ is not included by itself as an explanatory variable.

Table 4
Correlation table

Variable	Description	$p_{i,t}$	$Mat_{i,t}$	$Serv_{i,t}$	$\hat{q}_{i,t}$	$(1 - \hat{G}_{i,t+1})$	$t\hat{D}LL_{i,t}$	$(1 - \hat{G}_{i,t+1})t\hat{D}LL_{i,t}$	$Cat_{i,t}$	$\ln[Alt_i/1000]$
$p_{i,t}$	Price	1.000								
$Mat_{i,t}$	Cost of materials	0.816** (0.00)	1.000							
$Serv_{i,t}$	Cost of services	0.401** (0.00)	0.387** (0.00)	1.000						
$\hat{q}_{i,t}$	Instrument for overnight stays sold	0.059 (0.40)	-0.039 (0.58)	0.028 (0.69)	1.000					
$(1 - \hat{G}_{i,t+1})$	Proxy for the underinvestment effect	-0.325** (0.00)	-0.223** (0.00)	-0.148** (0.03)	-0.258** (0.00)	1.000				
$t\hat{D}LL_{i,t}$	Proxy for the DLL-effect ¹	-0.093 (0.18)	0.140** (0.04)	0.230** (0.00)	-0.042 (0.54)	-0.484** (0.00)	1.000			
$(1 - \hat{G}_{i,t+1})t\hat{D}LL_{i,t}$		-0.094 (0.18)	0.021 (0.76)	0.183** (0.01)	-0.081 (0.24)	-0.060 (0.39)	0.558** (0.00)	1.000		
Cat_i	Dummy for high-quality hotels	0.168** (0.02)	-0.003 (0.97)	-0.023 (0.74)	0.328** (0.00)	0.012 (0.86)	-0.040 (0.57)	0.007 (0.92)	1.000	
$\ln[Alt_i/1000]$	$\ln$ [Altitude of closest meteorological station]	0.004 (0.96)	-0.146** (0.04)	-0.278** (0.00)	0.154** (0.03)	0.126* (0.07)	-0.141** (0.04)	0.105 (0.13)	0.118* (0.09)	1.000

This table reports the correlation coefficients for the correlations between any two variables included in our second-stage regressions. The sample includes 151 Austrian hotels and 209 firm-years during the period 1999–2002. $p_{i,t}$ is the average price that hotel i charged for one overnight stay in the year t , $Mat_{i,t}$ and $Serv_{i,t}$ are marginal costs, i.e., the cost of raw material required for cooking and cleaning, and the labor cost of any services that the hotel offers to its guests, respectively. $\hat{q}_{i,t}$ denotes the instrument for the sales of hotel i , i.e., the number of nights for which tourists stayed in the hotel during the year t . $(1 - \hat{G}_{i,t+1})$ is a proxy for the probability with which hotel i remains solvent in period $t + 1$. This variable is included in the second-stage regressions as a measure of the underinvestment effect of leverage on the pricing decisions of a firm. $t\hat{D}LL_{i,t}$ is a proxy for the variable $tDLL_{i,t}$, which measures the dynamic limited liability effect of leverage on the pricing decisions of a firm. See column (2) of Table 3 for the distributions of $\hat{G}_{i,t+1}$ and $t\hat{D}LL_{i,t}$. Cat_i denotes an indicator variable, which equals one if hotel i offers high-quality accommodation, rated four or five stars out of five. $\ln[Alt_i/1000]$ denotes the logarithm of the altitude of the meteorological station closest to hotel i , which serves as a proxy for the altitude of ski resorts in the proximity of the hotel. P -values are stated in parentheses. **(*) indicates correlation coefficients that are significantly different from zero, at a 95% (90%) level of significance.

¹ DLL-effect, dynamic limited liability effect.

Table 5
Second-stage estimates

Dependent variable: Price $p_{i,t}$					
Variable	Description	Coefficient	(1)	(2)	(3)
<i>Constant</i>	Constant	γ_0	-48.408 (1.13)	-55.638 (1.26)	-59.325 (1.37)
$Mat_{i,t}$	Cost of materials	γ_{1M}	1.466 (9.82)**	1.363 (9.20)**	1.385 (9.34)**
$Serv_{i,t}$	Cost of services	γ_{1S}	7.331 (4.39)**	7.709 (4.55)**	7.979 (4.76)**
$\frac{\hat{q}_{i,t}}{1000}$	Instrument for the number of overnight stays sold in the current year	γ_2	-0.389 (1.78)*	-0.318 (1.37)	-0.299 (1.31)
$(1 - \hat{G}_{i,t+1}) \times \frac{\hat{q}_{i,t+1}}{1000}$	Proxy for the underinvestment effect $\times$ instrument for the number of overnight stays sold in the next year	γ_U		-0.325 (1.45)	-0.486 (2.07)**
$(1 - \hat{G}_{i,t+1}) \times t\hat{DLL}_{i,t} \times \frac{\hat{q}_{i,t+1}}{1000}$	Proxy for the underinvestment effect $\times$ proxy for the DLL-effect ¹ $\times$ instrument for next year's sales	γ_D			-1.391 (2.20)**
$\ln[Alt_i/1000]$	$\ln$ [Altitude of closest meteorological station]	γ_3	13.267 (2.08)**	14.878 (2.25)**	15.602 (2.40)**
Cat_i	Dummy for high quality hotels	γ_4	21.660 (3.64)**	22.869 (3.72)**	23.197 (3.85)**
σ_κ	Standard deviation of random effects		20.431	20.571	19.958
σ_w	Standard deviation of residuals		6.752	6.397	6.420
R^2			0.634	0.621	0.646
p: $\gamma_U = \gamma_D$	P-value for the hypothesis that $\gamma_U = \gamma_D$				0.131
	Number of observations (firm-years)		209	209	209
	Number of firms		151	151	151

This table reports indirect least squares (ILS) estimates with firm-specific random effects of the regression Equation (14). The sample includes 151 Austrian hotels and 209 firm-years during the period 1999–2002. The dependent variable is the average price $p_{i,t}$ that hotel i charged for one overnight stay in the year t . $Mat_{i,t}$ and $Serv_{i,t}$ denote the cost of raw materials required for cooking and cleaning, and the labor cost of any services that the hotel offered to its guests. $\hat{q}_{i,t}$ denotes an instrument for the sales of hotel i , i.e., the number of nights for which tourists stayed in the hotel during year t . $(1 - \hat{G}_{i,t+1})$ denotes a proxy for the probability with which hotel i remains solvent in period $t + 1$. This variable is included in the second-stage regressions as a measure of the underinvestment effect of leverage on the pricing decision of hotel i in year t . $t\hat{DLL}_{i,t}$ is a proxy for the variable $tDLL_{i,t}$, which measures the dynamic limited liability effect of leverage on the pricing decision of hotel i in year t . See column (2) of Table 3 for the distributions of $\hat{G}_{i,t+1}$ and $t\hat{DLL}_{i,t}$. $\ln[Alt_i/1000]$ denotes the logarithm of the altitude of the meteorological station closest to hotel i , which serves as a proxy for the altitude of ski resorts in the proximity of the hotel. Cat_i denotes an indicator variable, which equals one if hotel i offers high-quality accommodation. Column (1) reports benchmark estimates in which γ_U and γ_D are restricted to be zero. In column (2) only γ_D is restricted to be zero. Column (3) presents estimates for the full model (14) in which neither γ_U nor γ_D are restricted to be zero. Absolute values of the z -statistics are stated in parentheses, based on adjusted standard errors. ** (*) indicates coefficients that are significantly different from zero, at a 95% (90%) level of significance.

¹DLL-effect, dynamic limited liability effect.

the hypothesis H_{UD} . The hotels' prices decrease not only in the nondefault probability $(1 - \hat{G}_{i,t+1})$ that captures the underinvestment effect, but also in the variable $t\hat{DLL}_{i,t}$ that captures the DLL effect. If $t\hat{DLL}_{i,t} > 0$ then our estimates suggest that the DLL effect leads the owner of firm i to reduce the

current price and thus invest in customer base in the current period. This result is quite intuitive. Referring back to Equations (7) and (12), $t\hat{DLL}_{i,t} > 0$ means that $DLL_{i,t} < 1$, which means that the default probability is higher in the next period than in the current period. Thus, as is predicted in our theory, we find evidence that the DLL effect leads owners to set lower prices, and thus invest in customer base, just prior to an increase in the default probability. As discussed above, this is a form of dynamic risk-shifting. The DLL effect counteracts (reinforces) the underinvestment effect if the present period's debt due is lower (higher) than the debt that will be due in the following period.

The estimates in column (3) can be used to judge the economic significance of the underinvestment effect and the DLL effect. Consider a hotel that has the median values of zero for both the default probability $\hat{G}_{i,t+1}$ and the variable $t\hat{DLL}_{i,t}$ (see column 2 of Table 3), and the mean number of overnight stays per year (about 17,500). If the default probability for such a hotel increases by one standard deviation (0.33), then the hotel will raise its price by $0.486 \times 0.33 \times (17,500/1000) = 2.81$ Euros. This change is due to the underinvestment effect. For the same hotel, leaving the default probability at zero, a one standard deviation change in the $t\hat{DLL}_{i,t}$ variable leads to a price change of $1.391 \times (1 - 0.000) \times 0.210 \times (17,500/1000) = 5.11$ Euros. This change is due to the DLL effect. Relative to the average room rate for the hotels in our sample, these price changes represent relative changes of approximately 3.6% and 6.5%, respectively. The overall effect, however, depends on whether the DLL effect reinforces or ameliorates the underinvestment effect.

3.5 Robustness checks

In this section, we check the robustness of our results to two assumptions that we have made in calculating the default triggers. All of the results presented in Tables 4 and 5 are based on the following two assumptions: (i) firms must pay an amount equal to 10% of their nominal short-term debt in order to avoid default, and (ii) the firms' owners will, if necessary, inject cash up to the book values of their equity stakes.

To check the validity of the second assumption, we have gathered data about financially distressed hotels that managed to avoid bankruptcy. We have obtained such data for 27 hotels, none of which are included in the dataset described so far.³⁴ In 17 cases, we observed that the resolution of financial distress involved cash injections by the firms' owners, as is assumed in our theoretical analysis. The amount of cash injected seems to be mainly determined by the owners' wealth in the form of real estate holdings; 97% of the cash injections were financed through selling privately held real estate. We find that there are, however, additional ways of refinancing in financial distress, such as debt concessions on the part of the hotels' banks. It appears that equity

³⁴ As discussed above, none of the hotels in that data set had entered into financial distress. The data discussed here were provided to us by the bank that also provided us with the data used above, i.e., the Austrian Tourism Bank.

financing is the marginal source of financing for a hotel in financial distress, if the hotel's owners are able to provide the financing by selling other real estate. As such, the book value of a hotel's equity is an upper bound on the amount of capital that the hotel's owners will inject in order to avoid losing their equity stakes through a default of the hotel.

In order to correct any bias that may result from our assumption regarding the hotels' access to capital injections from their owners we would need data about the owners' personal wealth. We would also need data regarding the concessions that the owners can obtain from their banks; however, such data is not available to us. We can only check that our results are robust by varying our assumptions.

In Table 6, we rerun the regression that is reported in column (3) of Table 5, but with different assumptions regarding the values of the variables in expression (16) that is used to calculate the default triggers $\underline{x}_{i,\tau}$ (where $\tau \in \{t, t+1\}$). In all of the regressions of Table 5, we assume that $d_{i,\tau}$ is 10% of the nominal short-term debt and $\beta V_{i,\tau+1}$ is the current (time τ) book value of equity. In columns (1) and (2) of Table 6, we maintain the assumption that $\beta V_{i,\tau+1}$ is the current book value of equity, but in column (1) we assume that $d_{i,\tau}$ is 100% of the nominal short-term debt. In column (2), we assume that $d_{i,\tau}$ is zero, so that the hotels are only required to pay their fixed costs in order to avoid a default. Using different values for $d_{i,\tau}$ results in different values for the default trigger, $\underline{x}_{i,\tau}$, and thus different values for the proxies for the default probability $G_{i,t+1}$ and the variable $t\hat{D}LL_{i,t}$. The distributions of these proxies are reported in columns (1) and (3) of Table 3.

In columns (3) and (4) of Table 6, we check the robustness of our results to the assumption that the firms in our sample can rely on their owners for cash injections up to an amount equal to the book value of the equity. For the regressions in these two columns, we set $\beta V_{i,\tau+1}$ equal to zero in expression (16), effectively assuming that the firms' owners will not inject cash into their firms. In column (3), we further assume that $d_{i,\tau}$ is 10% of the nominal short-term debt (as in Table 5); in column (4), we assume that $d_{i,\tau}$ is zero. The distributions of the proxies for the default probabilities and the variable $tDLL_{i,t}$ that result from these assumptions are reported in columns (4) and (5), respectively, of Table 3.

Comparing the results of Table 6 with those of column (3) of Table 5, we find that our results are robust to changes in our assumptions regarding how much of the short-term debt must be paid, and regarding whether the firms' owners are willing and able to inject equity capital. In all the regressions of Table 6, we continue to find evidence consistent with hypothesis **H_{UD}**.

The estimates in columns (2) and (4) of Table 6 can also be seen as a robustness check concerning the assumption that the hotels' financial structures are exogenously determined. The estimates in these columns are based on the assumption that the firms' short-term obligations consist only of fixed costs, i.e., that the hotels need not repay any of their—possibly endogenous—short-term

Table 6
Robustness checks

Variable	Description	Dependent variable: Price $p_{i,t}$			
		% Of nominal short-term that must be paid: Maximum capital input, as % of book equity:			
		100%	0%	10%	0%
		(1)	(2)	(3)	(4)
$Constant$	Constant	-52.883 (1.26)	-58.242 (1.35)	-78.917 (1.61)	-79.277 (1.61)
$Mat_{i,t}$	Cost of materials	1.507 (10.10)**	1.353 (9.19)**	1.072 (7.77)**	1.046 (7.67)**
$Serv_{i,t}$	Cost of services	7.482 (4.53)**	8.143 (4.88)**	7.909 (4.55)**	8.005 (4.61)**
$\frac{\hat{q}_{i,t}}{1000}$	Instrument for the number of overnight stays sold in the current year	-0.282	-0.281	-0.341	-0.318
$(1 - \hat{G}_{i,t+1}) \times \frac{\hat{q}_{i,t+1}}{1000}$	Proxy for the underinvestment effect $\times$ instrument for the number of overnight stays sold in the next year	(1.31)	(1.23)	(1.32)	(1.22)
$(1 - \hat{G}_{i,t+1}) \times t\hat{D}LL_{i,t} \times \frac{\hat{q}_{i,t+1}}{1000}$	Proxy for the underinvestment effect $\times$ proxy for the DLL-effect ¹ $\times$ instrument for next year's sales	-0.473 (2.30)**	-0.641 (2.56)**	-1.784 (5.11)**	-1.769 (5.14)**
$\ln[Alt_i/1000]$	$\ln$ [Altitude of closest meteorological station]	-1.072	-1.610	-4.345	-4.261
Cat_i	Dummy for high quality hotels	(1.96)** 14.258 (2.26)**	(2.16)** 15.669 (2.42)**	(2.64)** 20.312 (2.75)**	(2.63)** 20.439 (2.76)**
σ_k	Standard deviation of random effects	21.906	23.439	30.015	30.010
σ_w	Standard deviation of residuals	(3.69)** 19.741	(3.90)** 19.945	(4.54)** 19.931	(4.55)** 19.934
R^2	P -value for the hypothesis that $\gamma_U = \gamma_D$	0.670	0.642	0.595	0.591
$p:\gamma_U = \gamma_D$	Number of observations (firm-years)	0.270	0.176	0.099	0.103
	Number of firms	209	209	209	209
		151	151	151	151

This table reports robustness checks of the results in column (3) of Table 5. The Table 5 results were based on the assumptions that the firms in our sample must pay 10% of their short-term debt, and that the firm's owners stand ready to inject new capital. Columns (1) and (2) below present estimates obtained by assuming that the firms must pay 100% of their short-term debt (column (1)) or none of this debt (column (2)). Columns (3) and (4) present estimates for the case in which the firms' owners cannot inject new capital, and the firms must pay 10% of their short-term debt (column (3)) or none of this debt (column (4)). Each set of estimates is based on different values of the proxies for the underinvestment effect, and the DLL-effect,¹ i.e., the nondefault probability $(1 - G_{i,t+1}[\Sigma_{i,t+1}])$ and the variable $tDLL_{i,t}$, respectively. The distributions of these proxies are reported in Table 3, where column (1) presents the distributions of the proxies used in column (1) of the present table, column (3) describes the proxies used below in column (2), column (4) describes the proxies used below in column (3), and column (5) describes the proxies used in column (4) below. Absolute values of the z -statistics are stated in parentheses, based on adjusted standard errors. ** (*) indicates coefficients that are significantly different from zero, at a 95% (90%) level of significance.

¹DLL-effect, dynamic limited liability effect.

debt. Thus, in these columns, we test only for the effect of operating leverage (i.e., leverage that is due to fixed costs of operation that are exogenously determined). A further possible source of endogeneity is removed in column (4). In this column, we not only assume that the firms' current obligations are equal to their fixed costs, but also that the hotels do not receive equity injections from their owners. This latter assumption removes a potential bias that is due to subtracting the possibly endogenous book values of the hotels' equity when computing the default trigger $\underline{x}_{i,\tau}$.

4. Conclusion

In this paper, we document likely reasons firms' pricing policies depend on their financial structures. We first identify two effects of leverage on firms' pricing strategies, and we then provide empirical evidence of both effects. The first effect, the underinvestment effect, occurs because owners of firms with more debt use a higher effective discount rate when valuing future expected returns on current investments. As a result, they are less willing to lower their current prices in order to invest in market share. The second effect, the DLL effect, occurs because firm owners have incentives to engage in risk shifting, and an investment in market share shifts risk exposure from the current to the next period. The DLL effect induces owners to increase (decrease) the firm's investment in market share if the current debt obligation will be higher (lower) in the next period than in the present period. This policy is a dynamic form of risk-shifting since the firm raises its exposure to demand uncertainty prior to an increase in its default probability. The debt maturity structure determines in which periods the DLL effect reinforces the underinvestment effect, and in which periods the two effects ameliorate each other.

Our empirical analysis provides direct evidence of both the underinvestment effect and the DLL effect. We thus document that a firm's pricing policy depends on its financial structure both through the probability with which the firm defaults and through the way in which the default probability varies over time. These results are obtained using data about a sample of firms in an industry that is ideal for testing the theory. Moreover, we use a structural empirical model that enables us to test simultaneously for the underinvestment effect and the DLL effect, and at the same time separate the two effects. This approach is necessary both because the effects are nonlinear and because their interaction is positive for some firm-years and negative for others.

The results of our analysis matter for future research. The theoretical analysis reveals that firms' pricing decisions depend on the interaction of two different effects of leverage that were previously analyzed in isolation. Moreover, we provide a new perspective on the "limited-liability effect" of leverage on firms' objective functions. Our dynamic view of this effect reveals that the direction of the effect typically varies over time, while one-period models suggest that the direction of the effect is determined by time-invariant characteristics of a firm's

industry. A key insight of this work is that, if both the cost of an investment and the future benefit are uncertain, then both the level of debt and the maturity structure of the debt will affect the optimal investment policy. This insight should be applicable to a wide range of investment decisions.

Appendix

Derivation of the Euler condition

The maximization problem in Equation (4) has the following first-order condition:

$$0 = (1 - F[\underline{\alpha}_t]) \left(E_t[\tilde{\alpha}_t] \frac{dx_t^*}{dp_t} + \beta V'_{t+1}[q^*[p_t, q_{t-1}^*]] \frac{dq_t^*}{dp_t} \right) + \frac{d\underline{\alpha}_t}{dp_t} (\underline{\alpha}_t x^*[p_t, q_{t-1}^*] - d_t + \beta V_{t+1}[q^*[p_t, q_{t-1}^*]]), \quad (\text{A1})$$

where $E_t[\tilde{\alpha}_t] = E[\tilde{\alpha}_t | \alpha_t \geq \underline{\alpha}_t]$. The second line of Equation (A1) is equal to zero (by the definition of $\underline{\alpha}_t$ in Equation (3)). To obtain an expression for the derivative $V'_{t+1}[\cdot]$, we apply the envelope theorem to determine the total derivative of the value function (4):

$$V'_{t+1}[q_{t-1}^*] = (1 - F[\underline{\alpha}_t]) \left(E_t[\tilde{\alpha}_t] \frac{\partial x_t^*}{\partial q_{t-1}^*} + \beta V'_{t+1}[q^*[p_t, q_{t-1}^*]] \frac{\partial q_t^*}{\partial q_{t-1}^*} \right) + \frac{\partial \underline{\alpha}_t}{\partial q_{t-1}^*} (\underline{\alpha}_t x^*[p_t, q_{t-1}^*] - d_t + \beta V_{t+1}[q^*[p_t, q_{t-1}^*]]), \quad (\text{A2})$$

The second line of Equation (A2) is also zero. Rearranging the first-order condition (A1) yields:

$$V'_{t+1}[q^*[p_t, q_{t-1}^*]] = -\frac{1}{\beta} E_t[\tilde{\alpha}_t] \frac{\frac{dx_t^*}{dp_t}}{\frac{dq_t^*}{dp_t}}. \quad (\text{A3})$$

By substituting this expression for $V'_{t+1}[q^*[p_t, q_{t-1}^*]]$ in the first line of expression (A2), we obtain the result:

$$V'_{t+1}[q_{t-1}^*] = (1 - F[\underline{\alpha}_t]) E_t[\tilde{\alpha}_t] \left(\frac{\partial x_t^*}{\partial q_{t-1}^*} - \frac{dx_t^*}{dp_t} \frac{\frac{\partial q_t^*}{\partial q_{t-1}^*}}{\frac{dq_t^*}{dp_t}} \right). \quad (\text{A4})$$

Upon adjusting the time-subscripts, we obtain a similar expression that can be used to substitute for $V'_{t+1}[q^*[p_t, q_{t-1}^*]]$ in the first-order condition (A1). By rearranging the resulting equation, we obtain the Euler equation:

$$\begin{aligned} E_t[\tilde{\alpha}_t] \frac{dx_t^*}{dp_t} + (1 - F[\underline{\alpha}_{t+1}]) \beta E_{t+1}[\tilde{\alpha}_{t+1}] \frac{\partial x_{t+1}^*}{\partial q_t^*} \frac{dq_t^*}{dp_t} \\ = (1 - F[\underline{\alpha}_{t+1}]) \beta E_{t+1}[\tilde{\alpha}_{t+1}] \frac{dx_{t+1}^*}{dp_{t+1}} \left(\frac{\frac{\partial q_{t+1}^*}{\partial q_t^*} \frac{dq_t^*}{dp_t}}{\frac{dq_{t+1}^*}{dp_{t+1}}} \right). \end{aligned} \quad (\text{A5})$$

In order to simplify the Euler condition (A5), we first divide both sides of the condition by the second term on the left-hand side:

$$\frac{1}{\beta(1 - F[\underline{\alpha}_{t+1}])} \frac{E_t[\tilde{\alpha}_t]}{E_{t+1}[\tilde{\alpha}_{t+1}]} \frac{\frac{dx_t^*}{dp_t}}{\frac{\partial x_{t+1}^*}{\partial q_t^*} \frac{dq_t^*}{dp_t}} + 1 = \frac{\frac{dx_{t+1}^*}{dp_{t+1}} \frac{\frac{\partial q_{t+1}^*}{\partial q_t^*} \frac{dq_t^*}{dp_t}}{\frac{dx_{t+1}^*}{\partial q_t^*} \frac{dq_t^*}{dp_t}}}{1} = 1 + \frac{q_{t+1}^*}{(p_{t+1} - c_{t+1}) \frac{dq_{t+1}^*}{dp_{t+1}}}.$$
(A6)

The second equation above is obtained by canceling terms after substituting for the derivatives $dx_{t+1}^*/dp_{t+1} = (p_{t+1} - c_{t+1})(dq_{t+1}^*/dp_{t+1}) + q_{t+1}^*$, $\partial x_{t+1}^*/\partial q_t^* = (p_{t+1} - c_{t+1})\lambda$, and $\partial q_{t+1}^*/\partial q_t^* = \lambda$. Next, we rearrange Equation (A6) in order to obtain expression (5).

Derivation of the econometric model

To derive the econometric model of the pricing policy, we substitute expression (6) for $MRI S_t$ in condition (5) and rearrange the condition in order to obtain the following equation:

$$\frac{dx_t^*}{dp_t} + \beta \frac{\partial x_{t+1}^*}{\partial q_t^*} \frac{dq_t^*}{dp_t} \frac{1}{\epsilon_{t+1}} (1 - F[\underline{\alpha}_{t+1}]) (1 + tDLL_t) = 0,$$
(A7)

where $tDLL_t = 1/DLL_t - 1$. Next, we substitute for the derivative dx_t^*/dp_t of the profit function $x^*[p_t, q_{t-1}^*] = (p_t - c_t)q^*[p_t, q_{t-1}^*]$, and rearrange the resulting expression in order to obtain:

$$p_t = c_t - \frac{q_t^*}{\frac{dq_t^*}{dp_t}} - \beta \frac{\frac{\partial x_{t+1}^*}{\partial q_t^*}}{\epsilon_{t+1}} (1 - F[\underline{\alpha}_{t+1}]) (1 + tDLL_t).$$
(A8)

Substituting further for $\epsilon_{t+1} = -(dq_{t+1}^*/dp_{t+1})(p_{t+1} - c_{t+1})/q_{t+1}^*$ and $\partial x_{t+1}^*/\partial q_t^* = (p_{t+1} - c_{t+1})\lambda$ yields Equation (11):

$$p_t = c_t - \frac{q_t^*}{(dq_t^*/dp_t)} + \beta \lambda \frac{q_{t+1}^*}{(dq_{t+1}^*/dp_{t+1})} (1 - F[\underline{\alpha}_{t+1}]) (1 + tDLL_t).$$
(A9)

Derivation of the proxy for $tDLL_{i,t}$

We can rewrite the definition (12) of $tDLL_{i,t}$ as follows:

$$tDLL_{i,t} = \frac{\frac{E_{i,t+1}[\tilde{\alpha}_{i,t+1}]}{E[\tilde{\alpha}_{i,t+1}]} - \frac{E_{i,t}[\tilde{\alpha}_{i,t}]}{E[\tilde{\alpha}_{i,t}]}}{\frac{E_{i,t}[\tilde{\alpha}_{i,t}]}{E[\tilde{\alpha}_{i,t}]}} ,$$
(A10)

where $E[\tilde{\alpha}_{i,t+1}] = E[\tilde{\alpha}_{i,t}]$ because the distribution F_i is assumed to be time-invariant. Next, we transform the above-stated expression in order to obtain a definition of $tDLL_{i,t}$ in terms of the expected profits of hotel i in the periods t and $t + 1$:

$$tDLL_{i,t} = \frac{\frac{E[\tilde{x}_{i,t+1}|x_{i,t+1} \geq \underline{x}_{i,t+1}]}{E[\tilde{x}_{i,t+1}]} - \frac{E[\tilde{x}_{i,t}|x_{i,t} \geq \underline{x}_{i,t}]}{E[\tilde{x}_{i,t}]}}{\frac{E[\tilde{x}_{i,t}|x_{i,t} \geq \underline{x}_{i,t}]}{E[\tilde{x}_{i,t}]}} ,$$
(A11)

since

$$\frac{E_{i,t}[\tilde{\alpha}_{i,t}]}{E[\tilde{\alpha}_{i,t}]} = \frac{E[\tilde{\alpha}_{i,t}|\alpha_{i,t} \geq \underline{\alpha}_{i,t}]x_{i,t}^*}{E[\tilde{\alpha}_{i,t}]x_{i,t}^*} = \frac{E[\tilde{\alpha}_{i,t}x_{i,t}^*|\alpha_{i,t} \geq \underline{\alpha}_{i,t+1}]}{E[\tilde{\alpha}_{i,t}x_{i,t}^*]} = \frac{E[\tilde{x}_{i,t}|x_{i,t} \geq \underline{x}_{i,t}]}{E[\tilde{x}_{i,t}]},$$
(A12)

where the first equality in Equation (A12) follows from the definition $E_{i,t}[\tilde{\alpha}_{i,t}] = E[\tilde{\alpha}_{i,t}|\alpha_{i,t} \geq \underline{\alpha}_{i,t}]$, and the last equality follows from Equation (2) and the equivalence relation $\alpha_{i,t} \geq \underline{\alpha}_{i,t} \Leftrightarrow x_{i,t} = \alpha_{i,t}x_i^*[p_{i,t}, q_{i,t-1}^*] \geq \underline{x}_{i,t}$ since $\underline{x}_{i,t} = \underline{\alpha}_{i,t}x_i^*[p_{i,t}, q_{i,t-1}^*]$.

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