Real Flexibility and Financial Structure: An Empirical Analysis

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I examine the empirical relation between real flexibility and financial structure. I test whether real flexibility increases debt capacity by lowering default risk and making assets more marketable or decreases debt capacity by facilitating risk shifting and asset substitution. I measure real flexibility as the sensitivity of marginal production and investment decisions to variations in the economic environment. I find that financial leverage is negatively related to production flexibility but positively related to investment flexibility. This split in results suggests that although asset substitution facilitated by investment flexibility can be prevented contractually, risk shifting facilitated by production flexibility is intractable.

This article investigates whether real flexibility in a firm's technology affects its financial structure. Production flexibility can increase debt capacity by allowing a firm to adjust its factor intensity, product mix, or production level to changing market conditions, thus lowering the risk of default. Investment flexibility can increase debt capacity by allowing a firm to expand or contract its capital stocks, thus lowering distress costs by making its collateral assets more liquid. However, real flexibility can decrease debt capacity if lenders believe shareholders will use these real options to risk shift or engage in asset substitution. Whether real flexibility supports or undermines financial policy is an open empirical question with several implications for ex ante lending and firm finance.[1]

I investigate this trade-off by regressing financial-structure ratios on indicators of real flexibility. I derive indicators of the production and

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[1] As discussed in Section 1 of the article, Mauer and Triantis (1994) and Aivazian and Berkowitz (1998) show how real flexibility can support financial policy. Mello and Parsons (1992) and Mauer and Ott (2000) show how real flexibility can undermine financial policy.

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investment flexibility featured in the real-options literature following standard methods of production economics and investment theory. I compute these indicators using comparative statics estimated from firms' first-order conditions for production and investment. I use plant-level data from the U.S. Census Bureau to estimate these indicators for firms in 18 manufacturing industries. I test for interactions between these indicators and three dimensions of financial structure: financial leverage (the mix of debt and equity), maturity structure (the mix of short- and long-term debt), and credit structure (the mix of private and public debt).

I find that production flexibility undermines financial policy, but investment flexibility supports it. Firms that can easily adjust their factor intensity, product mix, or level of production generally use less financial leverage, shorter maturities, and less public debt. These findings suggest that lenders rationally anticipate ex-post opportunism by shareholders and respond to these forms of production flexibility by tightening the terms of credit. This lowers the equilibrium level of financial leverage used by flexible firms and increases their reliance on short-term debt and monitored bank loans.

In contrast, I find that firms with flexible buildings and workforces use more financial leverage and public debt. This suggests that, unlike production flexibility, investment flexibility increases debt capacity by making collateral assets more liquid, while restrictive covenants on asset sales prevent asset substitution. The positive relation to workforce flexibility suggests that the ability to hire and fire workers lowers default risk, while factors such as labor specialization prevent risk shifting.

I assess the economic significance of these findings by observing how predicted financial structure ratios behave as I let individual real flexibility proxies vary while holding other regressors at their sample means. Among the real flexibility proxies I consider, the ability to adjust the level of production (volume flexibility) has the biggest impact on financial structure. I find that as volume flexibility rises from the 5th to 95th percentile, predicted total debt over total assets declines by 3.61% and predicted public debt over total debt falls 2.49%.

Prior studies show that small firms have proportionally more real options than do large firms. This implies deeper agency problems and lower debt levels for small firms [Smith and Watts (1992)]. I find that although small firms are more flexible than large firms, which is consistent with their having more real options, small firms carry slightly more debt than do large firms. The fact that small firms also rely more on short debt maturities and bank loans than do large firms suggests that short-term, monitored debt helps curb agency problems and raises small firms' total debt capacity.

One might expect real flexibility to benefit small firms more than large firms because small firms are less diversified and lack the access large firms have to financial markets. Real flexibility could prove critical to small firms in averting financial distress and supporting their financial policy by substituting for their lack of financial flexibility. Deep agency problems and low financial flexibility suggest sharper regression results for small firms. Contrary to this hypothesis, the relations I find between real flexibility and financial structure are concentrated among large rather than small firms.

I test whether real flexibility and financial flexibility are complements or substitutes using the range over which firms allow their financial structure ratios to vary as a proxy for financial flexibility. I find evidence of a positive relation between the time ranges of firms' financial structure ratios and their average real flexibility levels for the sample period. Since a wide time range in financial structure points to high recapitalization costs and low financial flexibility, this finding is consistent with a prediction by Mauer and Triantis (1994) that real and financial flexibility are substitutes.

This research contributes to several areas of financial economics. First, this study provides new insights on the determinants of financial structure, with implications for the choice of financial leverage [Harris and Raviv (1991), Rajan and Zingales (1995)], debt maturity structure [Diamond (1991), Stohs and Mauer (1996)], and the mix of private and public debt [Rajan (1992), Houston and James (1996)]. Second, real flexibility provides a novel, more structured approach to measuring asset specificity [Williamson (1988), Shleifer and Vishny (1992)], real options, and the ex post investment opportunity set [Smith and Warner (1979), Smith and Watts (1992)].

This study extends the empirical real-options literature by providing the first direct tests and evidence of interactions between real flexibility and financial structure.[2] The study also brings empirical evidence to the large body of theoretical real-options literature in finance and economics [see Dixit and Pindyck (1994) and Trigeorgis (1996) for surveys of the literature].

In addition, the study broadens our understanding of corporate risk management by highlighting real flexibility as an alternative risk management tool to diversification, derivatives, and insurance. The scope that firms have to manage risk through the exercise of real options embedded in their production and investment technologies has only begun to be examined in the risk management literature [see Kamara (1993), Mello, Parsons, and Triantis (1995), and Tufano (1998), for instance].

[2] Paddock, Siegel, and Smith (1988) value the option to wait on the price of offshore oil leases. Fisher, Heinkel, and Zechner (1989) test the range over which the financial leverage ratio is allowed to vary. Quigg (1993) estimates the value of the option to delay development of urban land. Berger, ofek, and Swary (1996) use the liquidity premia on traded firms' assets to estimate the option value of exit.

Finally, this article belongs to the literature on real and financial interactions. Evidence in studies by Chevalier (1995), Phillips (1995), Kovenock and Phillips (1997), and Zingales (1998) shows that financial structure conditions product market behavior under imperfect competition. I document an empirical link between flexible technology and financial structure even in competitively structured industries. My findings also relate to predictions by Dammon and Senbet (1988), Maksimovic and Zechner (1991), and Williams (1995) on the interaction of technology and financial leverage.

This article is organized as follows. Section 1 develops the theoretical relation between real flexibility and financial structure. Section 2 ties this discussion to the production-theoretic approach I use to derive real flexibility proxies. Section 3 describes the data and industry selection. Section 4 reports descriptive statistics. Section 5 covers the econometric approach and presents regression results. Section 6 concludes. Appendix A formalizes the optimization framework and econometric methods outlined in Section 2. Appendix B lists the manufacturing industries used in the study.

1. Real Flexibility and Financial Structure

Theory shows both positive and negative interactions between real flexibility and financial structure. I refer to these positive and negative interactions as the value and agency hypotheses. This section develops these competing hypotheses for three dimensions of financial structure: financial leverage (total debt divided by total assets), maturity structure (long-term debt divided by total debt), and credit structure (public debt divided by total debt).

I test the value and agency hypotheses by regressing these financial structure ratios (financial leverage, debt maturity, and credit structure) on indicators of firms' production flexibility (process, product, and volume flexibility) and investment flexibility (buildings, machinery, and workforce flexibility). I control for profitability (cash flow divided by total assets), risk (physical-capital stocks divided by total labor costs, and the standard deviation of cash flow divided by total assets), diversification (one minus the Herfindahl of the firm's output), and firm size (log of total assets).

1.1 Real flexibility and financial leverage

Some studies show a positive interaction between real flexibility and financial leverage. Mauer and Triantis (1994) use a contingent-claims model to show that real flexibility creates value by lowering default risk and expected reorganization and recapitalization costs. In their model, real flexibility also adds value by increasing debt capacity and the associated debt tax shield. Aivazian and Berkowitz (1998) derive similar results in a discrete-time model. These studies point to a positive relation between real flexibility and financial leverage, and form the basis of my value hypothesis.

Other studies show that real flexibility promotes ex post opportunism by broadening the menu of risky ventures available to shareholders. For example, Green and Talmor (1986), Mello and Parsons (1992), Mello, Parsons, and Triantis (1995), and Mauer and Ott (2000) model risk-shifting opportunities introduced by various forms of real flexibility such as production and investment options. Anticipating risk shifting and asset substitution, lenders respond to real flexibility with tight credit terms, causing flexible firms to demand less debt. These studies point to a negative relation between real flexibility and financial leverage, and form the basis of my agency hypothesis.[3]

1.2 Real flexibility and maturity structure

Theory is also divided on the nature of the relation between real flexibility and maturity structure (the mix of short- and long-term debt). In discussing maturity structure, Barnea, Haugen, and Senbet (1980) and Sharpe (1991) argue that shortening debt maturity mitigates risk shifting by allowing creditors to either withdraw funding or reset the terms of credit at short, regular intervals. Inasmuch as real flexibility facilitates risk shifting, these studies imply that flexible firms will carry shorter debt maturities than inflexible firms. However, Mello and Parsons (1992) and Mauer and Ott (2000) show that the agency costs of debt decrease as debt maturity lengthens. These two studies therefore imply that flexible firms will carry longer debt maturities than inflexible firms.[4]

1.3 Real flexibility and credit structure

In his model of credit structure (the mix of private and public debt), Diamond (1991) argues that firms resort to monitored bank loans until they acquire enough reputation capital in the credit markets to precommit against risk shifting. At that point, firms can issue public debt and avoid monitoring costs. Thus, by facilitating risk shifting, real flexibility also explains the existence of monitored debt. This means that flexible firms will rely more on bank debt and less on public debt. Diamond's model therefore suggests a negative relation between real flexibility and the ratio of public debt to total debt.

[3] To the extent growth options and asset tangibility are proxies for real flexibility, prior empirical studies of financial leverage generally support the agency hypothesis. For instance, Smith and Watts (1992) document a negative relation between growth options and financial leverage.

[4] Barclay and Smith (1995) and Guedes and Opler (1996) find that firms with growth options are more likely to hold or issue short-term debt. However, Stohs and Mauer (1996) find only weak support for the agency hypothesis.

Other studies show that by monitoring borrowers, private lenders can make informed concessions that help distressed firms avoid the underinvestment and overliquidation associated with public debt. This concessionary feature of monitored debt means that, unlike bonds, bank loans provide ex post financial flexibility [Gertner and Scharfstein (1991), Asquith, Gertner, and Scharfstein (1994).[5] This flexibility is not without its costs. In addition to monitoring costs, Sharpe (1990) and Rajan (1992) argue that banks can use their ex post information monopoly powers to extract rents. Since flexible firms can make real-side adjustments, they have less need for the flexible but costly terms of bank loans. In other words, flexible firms will rely less on bank debt and more on public debt, therefore suggesting a positive relation between real flexibility and the ratio of public debt to total debt.[6]

1.4 Real flexibility, asset specificity, and the investment opportunity set

Real flexibility also pertains to asset specificity and the investment opportunity set. Ceteris paribus, assets with multiple uses (production flexibility) are more marketable than dedicated production facilities. Assets that are easily redeployed (investment flexibility) are also more marketable. Predictions by Williamson (1988) and Shleifer and Vishny (1992) on asset specificity extend to my value hypothesis: real flexibility can support financial policy by making assets more marketable (less specific), thus increasing their liquidation value ex post and enhancing their collateral value ex ante. However, by making assets more marketable, real flexibility also expands the investment opportunity set [Smith and Warner (1979)]. This facilitates asset substitution since fungible assets can be replaced with riskier assets once funding is in place. Thus, consistent with my agency hypothesis, real flexibility can promote shareholder opportunism and undermine financial policy.

Actually measuring asset specificity presents an empirical challenge. Authors such as Titman and Wessels (1988) and Rajan and Zingales (1995) use the ratio of tangible to total assets as a proxy for asset marketability. Another common proxy is research and development (R&D) expenditures [Bradley, Jarrell, and Kim (1984), Barclay and Smith (1995)]. Since real flexibility and asset specificity are closely linked, the proposed indicators of real flexibility offer a more structured approach to gauging asset specificity. Measuring the firm's ex post investment opportunity set is equally problematic. However, under the gency interpretation, my indicators of real flexibility could also be viewed as proxies for the

[5] The ex post flexibility of monitored bank debt derives from banks' ability to make informed concessions that a dispersed group of uninformed investors cannot replicate. Asquith, Gertner, and Scharfstein (1994) find that "banks waive a covenant in 37 out of 45 technical covenant violations."

[6] Houston and James (1996) find that reliance on bank debt is negatively (positively) related to growth opportunities for firms with a single (multiple) banking relationship(s).

firm's ex post investment opportunity set [Smith and Watts (1992)]. Consequently this study makes a methodological contribution by suggesting new proxies for these elusive asset attributes.

These hypotheses, which relate real flexibility to asset specificity and the ex post investment opportunity set, do not require tests beyond those already formulated in the previous subsections. Rather these hypotheses suggest alternative interpretations for the same set of tests and results. Thus positive signs on the real flexibility indicators support the idea that more flexible (less specific) assets promise higher liquidation value ex post and command greater collateral value ex ante. Negative signs on the real flexibility indicators support the idea that by making assets more marketable, real flexibility expands the investment opportunity set and facilitates asset substitution.

2. Measuring Production and Investment Flexibility

In this section I derive and estimate real flexibility indicators from a simple optimizing framework and link these indicators to the value and agency hypotheses. The real optionality of the model derives from two sets of constraints. First, short-run production decisions are constrained by the production technology in place. Second, long-run investment decisions are constrained by adjustment costs, irreversibility, and time to build. The weight of these constraints can be inferred from how sensitive a firm's marginal production and investment decisions are to variations in the economic environment. I assess this sensitivity by estimating production and investment elasticities from industry-specific objective functions and use these elasticities as indicators of real flexibility. This section provides an overview of the optimization framework and its econometric implementation. Appendix A contains a full analytic derivation of the framework and more estimation details.

The real-options literature analyzes several forms of production and investment flexibility. Production flexibility includes switching between inputs and outputs [Kulatilaka (1988), Triantis and Hodder (1990)], varying the level of production [He and Pindyck (1992)], and starting or stopping operations [Brennan and Schwartz (1985)]. Investment flexibility includes entry and exit [Dixit (1989)], postponement [McDonald and Siegel (1986)], replacement [Mauer and Ott (1995)], abandonment [McDonald and Siegel (1985)], and the staging of investment [Baldwin (1982)].

I derive indicators of real flexibility to proxy for some of these production and investment options. For production flexibility, I use elasticities of substitution to measure the firm's ability to alter its factor intensity and product mix, and the elasticity of cash flow to output volume to measure its ability to vary production levels. For investment flexibility, I use the wedge between the actual and shadow rents of capital to measure the firm's ability to adjust its physical and human capital stocks. The rest of this section develops the model, the flexibility proxies, and their link to financial policy.

2.1 Optimization framework and econometric implementation

I assume a stochastic price-taking economic environment where firms solve two simultaneous optimization problems: (1) short-run (static) production decisions (the mix of inputs and outputs, and production levels), and (2) long-run (dynamic) investment decisions (capacity adjustments).

2.1.1 Production decisions. I assume that firms' short-run objective is to pick a production plan ($\mathbf{v}$) that maximizes expected period-t pre tax cash flow subject to their production technology, $\mathbf{V}(\dot{\mathbf{k}}, \mathbf{k})$, which is conditional on lagged capital stocks ($\mathbf{k}$) and concurrent investment decisions $\dot{\mathbf{k}}$, determined in Section 2.1.2):

$$\Pi(\mathbf{v} \mid \bar{\mathbf{p}}, \dot{\mathbf{k}}, \mathbf{k}, \beta) \equiv \max_{\mathbf{v}} E_t[\mathbf{p} \cdot \mathbf{v}(\mathbf{p}) \mid \mathbf{p}_{\tau<t}] \quad \text{subject to } \mathbf{v} \in \mathbf{V}(\dot{\mathbf{k}}, \mathbf{k}), \tag{1}$$

where

$\Pi(\cdot)$ is the maximum function for expected period-t pretax cash flow;

$\mathbf{v}$ is an n-vector of variable input factor and output product quantities: $\mathbf{v} \equiv \{Y, Z, L, P\}$;

$\bar{\mathbf{p}}$ is an n-vector of conditional expected year-end input and output prices, $\bar{\mathbf{p}} \equiv E_t\,[\mathbf{p} \mid \mathbf{p}_{\tau<t}]$;

$\mathbf{k}$ is an m-vector of lagged quasi-fixed capacity inputs (physical and human capital stocks);

$\dot{\mathbf{k}}$ is an m-vector of time derivatives of $\mathbf{k}$ (net investment), $\dot{\mathbf{k}} \equiv d\mathbf{k}/dt$;

$\mathbf{V}(\dot{\mathbf{k}}, \mathbf{k})$ is a convex set of production possibilities defined over $\Re^n$, conditional on $\mathbf{k}$ and $\dot{\mathbf{k}}$; and

β is a vector of technology coefficients (to be estimated).

Given the available data, I assume that production decisions ($\mathbf{v}$) consist in setting yearly levels of two output products, Y and Z (a primary and secondary product), and two input factors, L and P (production labor and materials), taking capital stocks ($\mathbf{k}$) and investment ($\dot{\mathbf{k}}$) as given. Capital stocks ($\mathbf{k}$) include buildings (B), machinery (M), and workforce (W). I lag these to reflect time to build. Investment ($\dot{\mathbf{k}}$) refers to changes in building stocks ($\dot{B} \approx \Delta B$), machinery ($\dot{M} \approx \Delta M$), and workforce ($\dot{W} \approx \Delta W$). Production technology ($\mathbf{V}(\dot{\mathbf{k}}, \mathbf{k})$) delimits input-output decisions and as such defines production flexibility. Less obviously, because it depends on capital stocks ($\mathbf{k}$) and investment ($\dot{\mathbf{k}}$), production technology also defines investment flexibility. This embeds an adjustment cost function in the objective function ($\Pi(\cdot)$) and, along with time to build, links investment decisions through time and forms the economic basis for the Euler equations developed below.

2.1.2 Investment decisions. In addition to solving their short-run production decisions, I assume that firms' long-run objective is to choose an investment path ($\{\dot{\mathbf{k}}_\tau\}_{\tau=t}^{\infty}$) that maximizes the expected present value of cash flow:

$$\max_{\{\dot{\mathbf{k}}_\tau\}_{\tau=t}^{\infty}} \int_t^{\infty} e^{-\rho\tau}[\Pi(\mathbf{v} \mid \mathbf{p}, \dot{\mathbf{k}}, \mathbf{k}, \boldsymbol{\beta}_t) - \mathbf{r} \cdot \mathbf{k}] d\tau \tag{2}$$

subject to transversality conditions (see Appendix A),

where:

r is an m-vector of market rental rates for the service flow of capacity inputs: $\mathbf{r} = \kappa \odot (\rho + \delta)$;

κ is an m-vector of relative prices of capacity inputs (buildings, machinery, workforce);

ρ is an m-vector of firm-specific risk-adjusted real discount rates (see Appendix A.4); and

δ is an m-vector of capacity depreciation rates.

This calculus of variations formulation follows the economic investment literature, represented by Hayashi (1982), Epstein and Denny (1983), Abel and Blanchard (1986), Whited (1992), etc. The firm's capacity accumulation path, $\{\dot{\mathbf{k}}_\tau\}_{\tau=t}^{\infty}$, determines the optimal net investment for period t ($\dot{\mathbf{k}}_t$).

2.1.3 Functional form and econometric implementation. The functional form I use is the symmetric generalized McFadden [Equation (A7) in Appendix A], proposed by Diewert and Wales (1987). The input quantities demanded and output quantities supplied by the firm follow from the envelope theorem (Hotelling's lemma) applied to Equation (1) [Equation (A9) in Appendix A]. The firm's net investment in capacity inputs derives from the first-order conditions (Euler equations) for Equation (2) [Equation (A10) in Appendix A]. I estimate these production and investment equations by running three-stage least squares regressions on plant-level data, by industry. I compute the flexibility indicators derived in Sections 2.2 and 2.3 from the estimated technology coefficients ($\hat{\beta}$), predicted prices ($\bar{\mathbf{p}}$), and year- and plant-specific values of the other variables ($\mathbf{v}, \dot{\mathbf{k}}, \mathbf{k}$). I aggregate these indicators to the firm level by averaging across each firm's plants, using individual plant output levels as weights. I then match these firm-level real-flexibility indicators to firm-level financial data. I test the value and agency hypotheses formulated in Section 1 by regressing the financial structure ratios on the real flexibility indicators.

2.2 Production flexibility: measurement and implications for financial policy

I use empirical comparative statics on the estimated objective function to measure three forms of production flexibility: process, product, and volume flexibility.

2.2.1 Process flexibility. I use the elasticity of substitution between labor and materials as a proxy for process flexibility:

$$\epsilon_{LP} \equiv \frac{L}{L+P}\left(\hat{\Pi}_{LP} - \hat{\Pi}_{PP}\right) + \frac{P}{L+P}\left(\hat{\Pi}_{PL} - \hat{\Pi}_{LL}\right), \tag{3}$$

where $\hat{\Pi}_{..}$ denotes the empirical second partial and cross-partial derivatives of the estimated objective function with respect to the price of production labor and materials (p_L, p_P). Following Chambers (1994), I compute these partial derivatives from the estimated technology coefficients ($\hat{\beta}$), predicted prices ($\bar{\mathbf{p}}$), and year- and plant-specific values of the other variables $(Y, Z, \dot{\mathbf{k}}, \mathbf{k})$.

2.2.2 Product flexibility. I use the elasticity of substitution between the two main products as a proxy for product flexibility:

$$\epsilon_{YZ} \equiv \frac{Y}{Y+Z}\left(\hat{\Pi}_{YZ} - \hat{\Pi}_{ZZ}\right) + \frac{Z}{Y+Z}\left(\hat{\Pi}_{ZY} - \hat{\Pi}_{YY}\right) \tag{4}$$

where $\hat{\Pi}_{..}$ denotes the empirical second partial and cross-partial derivatives of the estimated objective function with respect to the price of the primary and secondary output products (p_Y, p_Z). I compute these empirical partial derivatives from the estimated technology coefficients ($\hat{\beta}$), predicted prices ($\bar{\mathbf{p}}$), and year- and plant-specific values of the other variables $(L, P, \dot{\mathbf{k}}, \mathbf{k})$.

2.2.3 Volume flexibility. I use the elasticity of cash flow to output level ($Q = Y + Z$) as a proxy for volume flexibility:

$$\epsilon_{\Pi Q} \equiv \left.\frac{\partial \ln \hat{\Pi}(\cdot)}{\partial \ln Q}\right|_{\mathbf{v},\mathbf{p},\dot{\mathbf{k}},\mathbf{k}} = \left.\frac{\partial \hat{\Pi}(\cdot)}{\partial Q}\frac{Q}{\hat{\Pi}(\cdot)}\right|_{\mathbf{v},\mathbf{p},\dot{\mathbf{k}},\mathbf{k}}, \tag{5}$$

where $\hat{\Pi}(\cdot)$ denotes predicted cash flow. I compute this elasticity from the technology coefficients ($\hat{\beta}$), predicted prices ($\bar{\mathbf{p}}$), and year- and plant-specific values of the other variables $(\mathbf{v}, \dot{\mathbf{k}}, \mathbf{k})$. This elasticity measures the degree of output homogeneity, or linearity, of the production technology.

Volume flexibility increases as $abs[ln(\epsilon_{\Pi Q})] \to 0$, indicating a perfectly linear, flexible technology.

2.2.4 Implications of production flexibility for financial policy. Process flexibility enables firms to respond to changes in relative factor prices by substituting cheaper inputs for more expensive ones. For instance, production technology permitting, firms use more labor and less materials if the price of materials rises relative to wages. Similarly product flexibility enables firms to adapt to relative product price innovations by switching to higher value-added products. Volume flexibility enables firms to adjust their output to variations in supply and demand conditions, scaling back production under adversity, and boosting output in good times.

These responses typify behavior under the value hypothesis: Firms use production flexibility to maximize expected cash flow. However, under limited liability, shareholders also benefit from increases in the volatility of cash flow. Green and Talmor (1986) show that the fraction of shareholder wealth that derives from the volatility of cash flow increases with debt. Limited liability and debt financing therefore promote risk shifting, possibly through the opportunities that production flexibility presents. Process and product flexibility allow firms to risk shift by favoring risky production strategies over low volatility input and output combinations. Volume flexibility enables firms to bet on positive demand shocks by increasing production as market conditions become more volatile. These responses typify the behavior set out under the agency hypothesis.

2.3 Investment flexibility: Measurement and implications for financial policy

I measure investment flexibility as the wedge between the actual and shadow rents of capital. This is a variant of Tobin's marginal q: The marginal product of capital is compared to its marginal cost. This generates proxies for the flexibility of a firm's building stock, its machinery stock, and its workforce. Flexibility increases as the wedge between the actual and shadow rents of capital decreases.

2.3.1 Measuring investment flexibility. I define the actual capital rent as

$$\hat{\Pi}^A \equiv \hat{\Pi}(\cdot) - \mathbf{r} \cdot \mathbf{k} = \hat{\Pi}(\cdot) - r_B B - r_M M - r_W W \tag{6}$$

and the shadow capital rent as:

$$\hat{\Pi}^S \equiv \hat{\Pi}(\cdot) - \mathbf{s} \cdot \mathbf{k} = \hat{\Pi}(\cdot) - s_B B - s_M M - s_W W, \tag{7}$$

where

- $\mathbf{r}$ is a vector of capital *market* returns: $\mathbf{r}], \equiv [r_B r_M r_W]'$ and $r_j \equiv \kappa_j(\rho+\delta_j)$
- $\mathbf{s}$ is a vector of capital *shadow* returns: $\mathbf{s} \equiv [\hat{\Pi}_B \; \hat{\Pi}_M \; \hat{\Pi}_W]'$ and $\hat{\Pi}_j \equiv (\partial \text{In}\, \hat{\Pi}(\cdot))/(\partial \ln k_j) \mid_{\mathbf{p}, \dot{\mathbf{k}}, \mathbf{k}_{-kj}}$

for three quasi-fixed capacity inputs: buildings (B), machinery (M), and workforce (W);

κ_j is the relative purchase price of capacity input k_j (from the Bureau of Economic Analysis);

ρ is the firm-specific risk-adjusted real discount rate (see Appendix A.4);

δ_j is the depreciation rate of capacity input k_j (from the Bureau of Economic Analysis);

$\hat{\Pi}(\cdot)$ denotes predicted cash flow; and $\hat{\Pi}_j$ is the empirical partial derivative of the objective function with respect to capacity input k_j. I compute $\hat{\Pi}(\cdot)$ and $\hat{\Pi}_j$ from the technology coefficients $(\hat{\beta})$, predicted prices $(\bar{\mathbf{p}})$, and year- and plant-specific values of the other variables $(\mathbf{v}, \dot{\mathbf{k}}, \mathbf{k})$. Let

$$\hat{\Pi}_j^A \equiv \hat{\Pi}(\cdot) - r_j k_j, \quad \hat{\Pi}_j^S \equiv \hat{\Pi}(\cdot) - \hat{\Pi}_j k_j,$$
$$\text{and} \quad q_j \equiv \hat{\Pi}_j^A \div \hat{\Pi}_j^S \qquad \text{for } j \in \{B, M, W\}, \tag{8}$$

where r_j and $\hat{\Pi}_j$ denote the market and shadow returns on capital for capacity input k_j.

In equilibrium, capital shadow returns ($\mathbf{s}$) equal market returns ($\mathbf{r}$) and $\hat{\Pi}_j^S = \hat{\Pi}_j^A$: The firm is operating at long-run optimal capacity ($q = 1$). Consistent with the conventional interpretation of Tobin's marginal q, the firm should increase capacity (invest) if $q > 1$ and decrease capacity (divest) if $q < 1$. However, because of rigidities in the investment technology (irreversibilities, downtime, etc.), capital is costly to adjust and a certain degree of disequilibrium ($q \neq 1\ \forall t$) becomes economical. This introduces a wedge between the actual and shadow rents of capital. The greater (lower) these rigidities, the greater (smaller) the departures from long-run equilibrium, and the greater (smaller) the wedge between the actual and shadow rents of capital. Hence values of q near one indicate investment flexibility and values of q far from one indicate inflexible investment.

2.3.2 Implications of investment flexibility for financial policy. Investment flexibility, like production flexibility, has an ambiguous effect on financial structure. Under the value hypothesis, investment flexibility enables firms to adjust capacity to variations in the economic environment, downsizing or expanding as supply and demand conditions dictate. Investment flexibility also makes assets less specific and hence more marketable if liquidation becomes necessary. Therefore investment flexibility increases debt capacity by lowering distress costs and enhancing the collateral value of assets. This should also help firms issue long-term debt and improve access to public debt markets. However, under the agency hypothesis, investment flexibility decreases debt capacity by facilitating asset substitution if fungible assets can be replaced with riskier assets once funding is in place. For similar reasons, investment flexibility can mean shorter debt maturities and greater reliance on monitored bank debt to help curb agency problems.

2.4 Control variables

Prior studies document a strong inverse relation between financial leverage and profitability [Titman and Wessels (1988), Rajan and Zingales (1995)]. Since real flexibility helps firms weather exogenous shocks, flexible firms might be more profitable and hence carry less debt than inflexible firms. Therefore, to differentiate between the effects of real flexibility and profitability in explaining financial structure, my regressions control for cash flow divided by total assets.

Pindyck (1988) shows that how much a firm veers from optimal real capacity depends both on its investment flexibility and the level of volatility it faces. Mauer and Ott (2000) find that agency costs in the presence of a growth option and risky debt are inversely related to the level of volatility. Therefore, to differentiate between the effects of investment flexibility and risk in explaining financial structure, my regressions control for cash flow volatility and operating leverage.

Real flexibility provides firms with an alternative risk management tool to diversification, size, and hedging [Kamara (1993), Mello, Parsons, and Triantis (1995), Tufano (1998)]. Therefore, to differentiate between real flexibility and some of these other determinants of financial structure, my regressions control for diversification (one minus the Herfindahl of the firm's output) and firm size (log of total assets).

3. Data and Sample Selection

3.1 Data sources

My primary data sources are the Longitudinal Research Database (LRD) and the Quarterly Financial Reports (QFR), both maintained by the Center for Economic Studies at the Bureau of the Census (U.S. Department of Commerce). The LRD contains annual data for roughly 50,000 manufacturing plants in intercensus years and morethan 300,000 plants in census years. The intercensus data are from the Annual Survey of Manufacturers (ASM), comprising all plants with more than 250 employees and a randomly selected, five-year rotating subpanel of smaller plants. This random subpanel is drawn in census years and takes effect one year after the census. The LRD contains detailed plant-level data on flows and stocks of factor inputs and production outputs (e.g., fixed-capital stocks, cost of materials, value of shipments, employment numbers). The LRD covers both public and private firms, and each plant is classified by historical four-digit SIC code.

The QFR contains quarterly firm-level accounting data (balance sheet and income statement accounts) for all public and private firms above a cutoff size (measured by nominal assets), and a randomly selected, eight-quarter rotating subpanel of smaller firms, of which one-eighth is replaced each quarter. No census/intercensus year distinction is made. The certainty cutoff size was \$10 million from 1977 (Q1) to 1978 (Q2), \$25 million from 1978 (Q3) to 1988 (Q3), and \$50 million from 1988 (Q4) onward. A key procedure in creating the sample involved matching LRD and QFR data using a firm identifier common to both datasets. See MacKay (1998) for a detailed discussion.

3.2 Industry selection

I use competitively structured industries to comply with the price-taking assumption of the optimizing framework. I implement this criterion by retaining industries with an average output Herfindahl index of less than 20%. I keep well-defined industries by requiring that at least 80% of the average firm's four-digit SIC output belong to that industry. Using import and export data from the National Bureau for Economic Research (NBER) to compute import penetration, I also require that at least 70% of industry output be of domestic origin. Finally, to ensure representativeness, I choose industries in most of the two-digit SIC categories of the manufacturing sector (except SIC industries 21 and 26, which were dropped because of difficulties in reaching convergence for the profit function estimation). These selection criteria yield the 18 industries listed in Appendix B.

3.3 Sample construction

I conduct outlier detection as follows. After removing extreme data points, I calculate the deviation of each observation from the multivariate mean of all ratio-form variables (i.e., all but total assets). I drop observations that are more than two standard deviations away from the multivariate mean, causing the sample to drop from 7067 to 6513 firm-years. This technique improves on univariate winsorizing by incorporating the multivariate dimension of the data in identifying outliers.

The regressions presented in Section 5 control for firm fixed effects by first-differencing the variables. This eliminates the first year of data and firms that appear only once, lowering the sample count to 5892 firm-years. More observations are lost because the GMM regressions use second and third lags as instruments. The final sample forms an unbalanced panel of 3416 firm-years comprising 764 firms in the selected 18 manufacturing industries over the period 1977 to 1990.

There are advantages to working with an unbalanced panel: The number of observations is maximized and survivor bias is minimized as newly created or destroyed firms are allowed to enter and exit the sample. Besides this natural process of addition and attrition, sample dynamics and composition are also driven by two noneconomic phenomena. First, the LRD and QFR rely on random subpanels for small firms, but use complete coverage for large firms. This causes an overrepresentation of large firms in both datasets. Second, the process of matching LRD to QFR data worsens this size bias because the LRD and QFR random subpanels are drawn independently and following different refresh rates and size cutoffs. As a result, the final sample reflects higher LRD to QFR match rates and better panel balancing for large firms than for small firms, that is, 1261 small firm-years (comprising 361 firms) and 2155 large firm-years (comprising 403 firms). I classify a firm as small if its output is below the sample median, where output is the inventory-adjusted value of shipments deflated to 1972 levels using four-digit SIC NBER price deflators.

4. Descriptive Statistics

Table 1 presents summary statistics on the financial structure ratios, the real-flexibility proxies, and the control variables for the entire sample as well as for small- and large-firm subsets. The table reports parametric and nonparametric statistics for sample location (means and medians), dispersion (standard deviations and interquantile ranges), and variation (between- and within-firm). Table 2 presents partial Pearson (parametric) and Spearman (rank) correlation coefficients.

4.1 Financial structure ratios

Table 1 shows that total debt averages 25% of total assets. This seems rather low and probably reflects the presence of private firms not usually included in empirical studies of firm finance. The median is even lower (22%). Rajan and Zingales (1995) find that for 2583 nonfinancial U.S. firms listed on Global Advantage between 1987 and 1991, the average ratio of short-term debt to total assets is 7.4% and the average ratio of long-term debt to total assets is 23.3%. The total (30.7%) seems economically different from my finding of 25%. Surprisingly, although statistically significant, the difference in mean financial leverage between small (26%) and large (24%) firms is economically insignificant. In fact, the small- and large-firm medians do not even differ statistically.

The average ratio of long-term debt to total debt ("maturity structure") is 73%, which is close to the average reported by Rajan and Zingales (1995). The median value is much higher at 84%. The average ratios of public debt to total debt ("credit structure") are 56% overall, and 45% and 69% for small and large firms. The difference in medians is even more striking: 37% for small firms and 84% for large firms. These economically significant differences confirm that large firms have better access to public debt markets than do small firms. This is corroborated by my finding that small firms carry significantly shorter debt maturities than do large firms: small firms' long-term debt averages 68%, whereas large firms average 81%. Median values are, respectively, 80% and 86%.

Table 1
Descriptive statistics

	Location			Dispersion			Variation		
Sampled firms	All	Small	Large	All	Small	Large	All	Small	Large
Observations (firm-years)	3416 [343]	1261 [127]	2155 [216]	3416 [3416]	1261 [1261]	2155 [2155]	764 [2652]	361 [900]	403 [1752]
Financial structure									
Total debt/total assets	0.25 [0.22]	0.26 [0.23]	0.24 [0.22]$^{a,-}$	0.17 [0.16]	0.20 [0.19]	0.15 [0.13]^{a,a}	0.81 [0.19]	0.84 [0.16]	0.75 [0.25]
Long-term debt/total debt	0.73 [0.84]	0.68 [0.80]	0.81 [0.86]^{a,a}	0.29 [0.24]	0.32 [0.29]	0.24 [0.18]^{a,a}	0.75 [0.25]	0.78 [0.22]	0.65 [0.35]
Public debt/total debt	0.56 [0.63]	0.45 [0.37]	0.69 [0.84]^{a,a}	0.40 [0.72]	0.41 [0.72]	0.36 [0.46]^{a,a}	0.78 [0.22]	0.77 [0.23]	0.74 [0.26]
Production Flexibility									
Process flexibility	0.24 [0.27]	0.16 [0.17]	0.37 [0.48]^{a,a}	1.51 [0.59]	1.87 [0.78]	1.03 [0.37]^{a,a}	0.62 [0.38]	0.76 [0.24]	0.55 [0.45]
Product flexibility	−0.91 [−0.74]	−1.23 [−0.75]	−0.64 [−0.43]^{a,a}	2.08 [1.26]	2.43 [1.53]	1.63 [1.10]^{a,a}	0.73 [0.27]	0.82 [0.18]	0.60 [0.40]
Volume flexibility	0.14 [0.11]	0.12 [0.09]	0.15 [0.12]^{a,a}	0.12 [0.10]	0.10 [0.07]	0.16 [0.12]^{a,a}	0.59 [0.41]	0.61 [0.39]	0.57 [0.43]
Investment flexibility									
Buildings	0.03 [0.02]	0.02 [0.02]	0.04 [0.03]^{b,b}	0.08 [0.02]	0.07 [0.02]	0.11 [0.06]^{a,a}	0.55 [0.45]	0.66 [0.34]	0.44 [0.56]
Machinery	0.07 [0.05]	0.05 [0.03]	0.09 [0.05]^{a,a}	0.09 [0.05]	0.06 [0.04]	0.13 [0.07]^{a,a}	0.65 [0.35]	0.72 [0.28]	0.58 [0.42]
Workforce	0.16 [0.11]	0.13 [0.10]	0.17 [0.12]^{a,a}	0.18 [0.14]	0.14 [0.12]	0.19 [0.16]^{a,a}	0.58 [0.42]	0.67 [0.33]	0.48 [0.52]
Control variables									
Risk									
Operating leverage	2.86 [2.09]	2.39 [1.72]	3.39 [2.47]^{a,a}	2.62 [1.62]	2.27 [1.44]	2.89 [1.75]^{a,a}	0.79 [0.21]	0.82 [0.18]	0.77 [0.23]
Cash flow volatility	0.06 [0.03]	0.07 [0.05]	0.04 [0.03]^{a,a}	0.07 [0.03]	0.08 [0.04]	0.04 [0.02]^{a,a}	0.90 [0.10]	0.90 [0.10]	0.88 [0.12]
Profitability									
Cash flow/total assets	0.12 [0.10]	0.10 [0.08]	0.13 [0.12]^{c,c}	0.09 [0.08]	0.11 [0.09]	0.08 [0.07]^{a,a}	0.65 [0.35]	0.69 [0.31]	0.60 [0.40]
Diversification									
1–Output Herfindahl	0.28 [0.02]	0.13 [0.00]	0.45 [0.50]^{a,a}	0.31 [0.48]	0.22 [0.00]	0.31 [0.41]^{a,a}	0.89 [0.11]	0.79 [0.21]	0.88 [0.12]
Size									
Total assets ($MM)	349 [50]	63 [17]	676 [197]^{a,a}	1165 [119]	242 [22]	1625 [345]^{a,a}	0.93 [0.07]	0.98 [0.02]	0.92 [0.08]

Sample location (means [quasi medians]), dispersion (standard deviations [interquantile ranges]), and variation (percentage between-firm [within-firm] variation) for firms in 18 manufacturing industries between 1977–1990. Firm size is relative to the sample median output level. Quasi medians, rather than true medians, are reported in order to comply with U.S. Census Bureau disclosure guidelines. These quasi medians are calculated as the average of observations in the 45th to 55th percentiles; they are very close to the true medians. Interquantile ranges are the absolute value of the difference between the means of observations in percentiles 69 and 31 (equivalent to one standard deviation under normality). Financial leverage is total debt divided by total assets (TD/TA), maturity structure is long-term debt divided by total debt (LD/TD), and credit structure is public debt divided by total debt (PD/TD). Elasticities of input and output substitution proxy for process and product flexibility. The absolute value of the log elasticity of cash flow to production level proxies for volume flexibility. The absolute value of the log ratio of the actual and shadow rents of capital proxies for investment flexibility (used for buildings, machinery, and workforce flexibility). Operating leverage is fixed-capital (buildings and machinery) divided by total labor costs (wages, salaries, and benefits). Cash flow volatility is the standard deviation of cash flow divided by mean total assets (using up to 20 quarters). Diversification is one minus the Herfindahl of output of a firm's four-digit SIC industries. Superscripts show tests of firm size differences in means (medians) assuming unequal variances (using a normal approximation) and *F*-tests of differences in variances (Moses tests of differences in dispersion).

[a,b,c]denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 2
Parametric and nonparametric partial correlations

		Spearman (nonparametric)														
Pearson (parametric)		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Financial structure																
Total debt/total assets	1	1.00	0.06	−0.12	–	–	−0.02	0.02	–	0.04	–	–	−0.23	0.08	−0.05	–
Long-term debt/total debt	2	0.11	1.00	0.21	–	−0.01	–	–	–	–	0.07	−0.05	0.10	–	0.14	–
Public debt/total debt	3	−0.11	0.27	1.00	–	–	−0.05	0.06	–	–	–	–	0.04	–	0.19	−0.08
Production flexibility																
Process flexibility	4	–	–	–	1.00	–	0.04	0.05	−0.03	0.04	–	–	–	–	–	0.06
Product flexibility	5	–	−0.01	–	–	1.00	–	–	–	–	–	–	–	–	–	–
Volume flexibility	6	−0.01	–	−0.04	–	–	1.00	0.08	0.05	0.12	–	–	–	−0.08	0.10	0.05
Investment flexibility																
Buildings	7	–	–	0.05	–	–	0.11	1.00	0.27	0.08	−0.07	0.04	–	−0.09	–	–
Machinery	8	–	–	–	–	–	0.05	0.16	1.00	0.24	−0.12	0.09	–	–	−0.07	–
Workforce	9	0.02	–	–	–	–	0.08	0.05	0.21	1.00	0.16	0.05	–	–	−0.07	0.07
Control variables																
Risk																
Operating leverage	10	–	0.07	0.07	–	–	–	–	−0.12	0.10	1.00	−0.25	−0.06	−0.15	0.21	0.18
Cash flow volatility	11	0.04	−0.20	–	–	–	–	0.07	0.09	–	−0.14	1.00	−0.04	−0.24	−0.22	0.14
Profitability																
Cash flow/total assets	12	−0.24	0.11	0.04	–	–	–	–	–	−0.04	−0.04	−0.07	1.00	–	–	–
Diversification																
1-Output Herfindahl	13	–	0.07	0.15	–	–	−0.07	−0.08	−0.04	−0.05	−0.24	−0.04	–	1.00	0.50	–
Size																
Total assets ($MM)	14	−0.08	−0.04	0.14	–	−0.04	–	–	−0.06	−0.09	–	0.11	−0.07	0.16	1.00	0.11
Time (year)	15	0.03	–	−0.08	–	–	0.08	–	–	0.07	–	0.15	–	–	0.08	1.00

Sample partial correlations for firms in 18 manufacturing industries between 1977 and 1990. Each correlation controls for all other variables in the table. Parametric (Pearson) coefficients appear in the lower left triangle; nonparametric (Spearman) coefficients appear in the upper right triangle. Values shown are statistically significant are at the 5% level (otherwise omitted). Financial leverage is total debt divided by total assets (TD/TA), maturity structure is long-term debt divided by total debt (LD/TD), and credit structure is public debt divided by total debt (PD/TD). Elasticities of input and output substitution proxy for process and product flexibility. The absolute value of the log elasticity of cash flow to production level proxies for volume flexibility. The absolute value of the log ratio of the actual and shadow rents of capital proxies for investment flexibility (used for buildings, machinery, and workforce flexibility). Operating leverage is fixed-capital (buildings and machinery) divided by total labor costs (wages, salaries, and benefits). Cash flow volatility is the standard deviation of cash flow divided by mean total assets (using up to 20 quarters). Diversification is one minus the Herfindahl of output of a firm's four-digit SIC industries.

Table 2 shows statistically significant correlations between the components of financial structure. The parametric (nonparametric) correlation coefficients are 0.11 (0.06) between financial leverage and debt maturity,[7] −0.11 (−0.12) between financial leverage and credit structure, and 0.27 (0.21) between debt maturity and credit structure. These correlation patterns support recent theories of capital structure that show how firms can mitigate incentive and information problems through a judicious choice of financial structure. My findings suggest that a firm can raise its debt capacity and improve its access to public debt markets by lengthening the maturity of its debt contracts. However, it also appears that the more a firm relies on public debt, the less debt it assumes overall.

4.2 Indicators of production and investment flexibility

Table 1 shows that average process flexibility is 0.24, indicating that a 1% increase in the price of labor results in a 0.24% increase in the intensity of material inputs in the production process. Average product flexibility is −0.91, indicating that a 1% increase in the price of the primary product leads to a 0.91% reduction in the production of the secondary product. Average volume flexibility is 0.14, indicating that a 1% change in output causes a 0.14% variation in cash flow. Average investment flexibility levels are 0.03 for buildings, 0.07 for machinery, and 0.16 for workforce, indicating that adjustment costs cause deviations from long-run optimal capacity levels of 3%, 7%, and 16%.

I find that small firms are statistically and economically more flexible than large firms. Although large firms are more flexible on the input side (process flexibility of 0.16 for small firms, 0.37 for large firms), small firms are better able to customize their output mix (product flexibility of −1.23 against −0.64) and adjust production levels (volume flexibility of 0.12 against 0.15). Small firms are also more flexible than large firms in their ability to adjust capacity levels. For instance, small firms have significantly more leeway in adjusting their workforce (0.13 versus 0.17 for large firms), perhaps reflecting greater union penetration or worker entrenchment among large firms.

Finally, small firms are typically closer to long-run optimal physical capacity levels than are large firms (2% versus 4% deviations from long-run optimal building stocks, and 5% versus 9% deviations from long-run optimal machinery stocks). This suggests that small firms face lower adjustment costs, making them more flexible than large firms. This finding also supports Williams' (1995) industry equilibrium, in which large firms

[7] Barclay and Smith (1995) report a similar 0.12 Pearson correlation between financial leverage and the percentage of debt maturing in more than three years for a sample of 39,949 firm-years. Stohs and Mauer (1996) find a much stronger correlation (0.46) between financial leverage and debt maturity. However, their correlations do not control for covariates and could be overstating the true marginal association between financial leverage and debt maturity.

adopt large-scale, specialized, capital-intensive facilities, and small firms adopt flexible, labor-intensive technologies.

5. Multivariate Results and Analysis

This section presents and discusses the multivariate regression results. Section 5.1 motivates the econometric approach, Section 5.2 discusses findings for the entire sample, Section 5.3 partitions the sample by firm size, and Section 5.4 examines the relation between real and financial flexibility.

5.1 Econometric approach

Table 3 presents multivariate regression estimates for financial leverage (total debt divided by total assets, TD/TA), maturity structure (long-term debt divided by total debt, LD/TD), and credit structure (public debt divided by total debt, PD/TD). Regressors include the proxies for production and investment flexibility and control variables for risk, profitability, diversification, and firm size.

I use dummy variables to control for industry and year, and first-fdifferences for firm fixed effects. I do so for the following reasons. First, the real flexibility proxies are industry-specific because I construct them from the production and investment equations of Section 2, which are estimated by industry. Second, as documented in Tables 1 and 2, financial structure varied substantially over the sample period. I therefore control for year fixed effects. Finally, the panel dimension of the sample allows me to control for unobserved firm-specific determinants of financial structure, such as measurement error in the QFR and LRD, and estimation error in the real flexibility proxies.

Models by Maksimovic and Zechner (1991) and Williams (1995) show that financial structure and technology are jointly determined. Regressions of financial structure on real flexibility are therefore subject to endogeneity bias. I address this problem by instrumenting the first-differences of all variables by the second and third lags in levels of the variables. Because the sample is highly unbalanced, especially among small firms, this number of lags reflects a trade-off between reducing endogeneity bias, losing observations, and introducing large-firm and survivor biases.

The right-hand panel of Table 3 extends the analysis by including the remaining two financial structure ratios in each regression equation. I do so on theoretical, empirical, and econometric grounds. Theoretical work by Rajan and Winton (1995) and Mauer and Ott (2000) shows that financial leverage, maturity structure, and credit structure are simultaneously determined policies. My finding that these variables are correlated supports this conclusion. The empirical basis is work by Guedes and Opler (1996) and Stohs and Mauer (1996), who control for financial leverage in

Table 3
OLS and GMM regressions of financial-structure ratios on real flexibility

	OLS			GMM		
Dependent variables	TD/TA	LD/TD	PD/TD	TD/TA	LD/TD	PD/TD
Financial structure						
Total debt/total assets					0.26^{***}	0.26^{***}
					(0.03)	(0.04)
Long-term debt/total debt				0.13^{***}		0.35^{***}
				(0.01)		(0.02)
Public debt/total debt				-0.08^{***}	0.21^{***}	
				(0.01)	(0.02)	
Production Flexibility						
Process flexibility	−0.03	−0.05	−0.07	−0.03	-0.14^{*}	-0.11^{**}
	(0.02)	(0.05)	(0.05)	(0.03)	(0.08)	(0.05)
Product flexibility	−0.01	-0.05^{**}	−0.02	-0.03^{**}	-0.04^{**}	−0.01
	(0.01)	(0.02)	(0.02)	(0.01)	(0.02)	(0.01)
Volume flexibility	-0.01^{**}	0.01	-0.02^{**}	-0.02^{**}	0.00	-0.05^{***}
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Investment flexibility						
Buildings	0.13^{*}	0.15	0.29^{**}	0.35^{***}	0.15	0.58^{***}
	(0.07)	(0.11)	(0.14)	(0.10)	(0.17)	(0.20)
Machinery	−0.02	0.03	−0.14	0.21^{*}	0.27^{*}	−0.25
	(0.08)	(0.12)	(0.16)	(0.11)	(0.16)	(0.21)
Workforce	0.14^{**}	−0.05	−0.01	0.24^{***}	−0.04	0.25^{***}
	(0.06)	(0.09)	(0.12)	(0.09)	(0.14)	(0.02)
Control variables						
Risk						
Operating leverage	0.00	0.00	0.01^{*}	0.00	0.00	0.00^{*}
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Cash flow volatility	0.30^{***}	-0.36^{***}	−0.03	0.48^{***}	-0.50^{***}	0.21^{**}
	(0.06)	(0.09)	(0.1)	(0.05)	(0.09)	(0.10)
Profitability						
Cash flow/total assets	-0.34^{***}	0.24^{***}	0.26^{***}	-0.47^{***}	0.37^{***}	0.17^{*}
	(0.03)	(0.06)	(0.07)	(0.04)	(0.08)	(0.10)
Diversification						
1-Output Herfindahl	-0.04^{***}	-0.06^{***}	0.08^{***}	-0.04^{***}	-0.09^{***}	0.16^{***}
	(0.01)	(0.02)	(0.03)	(0.01)	(0.02)	(0.02)
Size (log of total assets)	0.03^{***}	0.06^{***}	0.04^{***}	0.02^{***}	0.05^{***}	0.02^{***}
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Adjusted R^2/Wald statistic	2.3%	0.4%	0.7%	722^{***}	629^{***}	221^{***}
Degrees of freedom	3376	3376	3376	3374	3374	3374
Hansen's J-statistic (16 dof)	NA	NA	NA	503^{***}	451^{***}	323^{***}

OLS and GMM regressions of the financial structure ratios on the real flexibility indicators, control variables, and industry and year dummies. The variables are first-differenced to control for firm fixed effects and, for GMM, instrumented by the second and third lagged levels of all variables. The dependent variables are financial leverage (total debt divided by total assets, TD/TA), maturity structure (long-term debt divided by total debt, LD/TD), and credit structure (public debt divided by total debt, PD/TD). Elasticities of input and output substitution proxy for process and product flexibility. The absolute value of the log elasticity of cash flow to production level proxies for volume flexibility. The absolute value of the log ratio of the actual and shadow rents of capital proxies for investment flexibility (used for buildings, machinery, and workforce flexibility). Operating leverage is fixed-capital (buildings and machinery) divided by total labor costs (wages, salaries, and benefits). Cash flow volatility is the standard deviation of cash flow divided by mean total assets (using up to 20 quarters). Diversification is one minus the Herfindahl of output of a firm's four-digit SIC industries. The GMM regressions use the Newey–West procedure to correct for heteroscedasticity and MA(1) autocorrelation introduced by first-differencing. Heteroscedastic-consistent (asymptotic) standard errors in parentheses for OLS (GMM).

***,**,* denote statistical significance at the 1%, 5%, and 10% levels, respectively.

explaining maturity structure, and Johnson (1997), who controls for financial leverage in explaining credit structure. The econometric implication of the jointness of these financial policies is that the consistency and efficiency of the estimates can be improved by simultaneous-equation estimation. Hence the right-hand panel of Table 3 presents results for GMM regressions. I emphasize the GMM results below because these address all the econometric issues just raised.

5.2 Findings

The first and fourth columns of Table 3 report heteroscedastic-consistent OLS and GMM results for financial leverage regressed on the real-flexibility proxies and the control variables. In both cases, many of the real-flexibility coefficients are statistically significant, some at the 1% confidence level. Because the dependent variables fall in the [0, 1] range, I also estimated unreported two-limit Tobit regressions; results were qualitatively similar to the OLS and GMM estimates reported in Table 3.[8]

A notable feature of the GMM results is that all the production flexibility coefficients have negative signs, which supports the agency hypothesis that real flexibility interferes with financial policy, whereas all the investment flexibility coefficients have positive signs, which supports the value hypothesis that real flexibility supports financial policy. How can we explain this split in results?

One might argue that production flexibility facilitates *risk shifting*, which is hard to contract away, whereas investment flexibility facilitates *asset substitution*, which is easier to prevent contractually. Collateral pledges and restrictive covenants might suffice to prevent shareholders from replacing marketable (flexible) collateral assets with riskier assets, thus deterring outright asset substitution. Hence investment flexibility can increase debt capacity by making assets more liquid and lowering distress costs because asset substitution is curbed contractually.[9] However, findings by Smith and Warner (1979) suggest that risk shifting facilitated by production flexibility might be intractable.

Smith and Warner (1979) report that bond covenants restrict investment decisions (asset sales, vertical and horizontal integration), but say nothing about production decisions such as the choice of inputs and

[8] As commonly happens, the Hansen *J*-statistics strongly reject the overidentifying restrictions. This could mean that the model is misspecified or that the instruments are correlated with the residuals. However, *J*-tests hold asymptotically and are known to overreject in finite samples [see Ferson and Foerster (1994), for instance]. Moreover, as discussed in Stock and Wright (2000), this problem worsens when the instruments are weakly correlated to the endogenous variables. Finally, Leamer (1983) shows that large-sample specification tests are sensitive to even small departures from the "true" model. Thus although I cannot rule out simultaneity bias or misspecification, the instruments I use seem plausible and the results offer useful insights.

[9] Consistent with my finding, Rajan and Zingales (1995) find a positive relation between asset tangibility and leverage, which they attribute to the role of collateral in reducing agency costs.

outputs or the level of production. Covenants on production could prove impractical (too many contingencies), ineffectual (production decisions are easily altered without additional external funding), even damaging (too restrictive). Hence shareholders could seek to risk shift through those aspects of the business where arm's-length creditors cannot pry, namely, production decisions. Lenders anticipate this behavior and tighten the terms of credit, inducing firms with unchecked managerial discretion (production flexibility) to borrow less and rely on monitored debt.

Results for credit structure (last column of Table 3) bolster this interpretation. I find that the ratio of public debt to total debt is negatively (positively) related to production (investment) flexibility (all but product and machinery flexibility are significant). Consistent with the explanation offered for the financial leverage results, one could argue that investment flexibility improves access to public debt markets — and reduces reliance on bank loans — by making collateral assets more liquid. However, because flexible production technology exposes lenders to risk shifting, firms with high production flexibility see their access to public debt curtailed. They resort to bank loans instead.

Both financial leverage and the public debt ratio are positively related to workforce flexibility. The ability to hire and fire workers at will might raise debt capacity because this flexibility lowers default risk, while risk shifting is curbed because factors like labor specialization prevent firms from reassigning their workers to materially different or riskier ventures. Asset substitution is not even a consideration here since firms do not own their workers as they do their physical capital stocks.

Results for the maturity structure regression concur with the above findings: negative signs for production flexibility (process and product flexibility are statistically significant) and positive signs for investment flexibility (only machinery flexibility is significant). Except for operating leverage, all the control variables enter significantly in the three regression models, and with signs consistent with prior empirical studies. Finally, financial leverage, maturity structure, and credit structure are all significantly related, consistent with the results of the correlation analysis (Table 2).

Table 4 examines economic significance, contrasting OLS and GMM estimates (panels A and B). It shows how the dependent variables behave when I vary individual explanatory variables and hold all other regressors at their sample means. This exercise reveals that, among the flexibility proxies, volume flexibility has the biggest impact on financial structure. Under OLS (GMM), the predicted ratio of total debt over total assets declines by 2.35% (3.61%) as volume flexibility goes from the 5^{th} to 95^{th} percentile; predicted public debt over total debt decreases 1.99% (2.49%). Although these individual effects appear modest, their collective impact on financial structure cannot be ignored.

Table 4
Economic significance of the relation between financial structure and real flexibility

	5th percentile			25th percentile			50th percentile			75th percentile			95th percentile		
Dependent variables:	TD/TA	LD/TD	PD/TD	TD/TA	LD/TD	PD/TD	TD/TA	LD/TD	PD/TD	TD/TA	LD/TD	PD/TD	TD/TA	LD/TD	PD/TD
Panel A: Using OLS coefficient estimates															
Production flexibility															
Process flexibility															
Product flexibility		0.56			0.13			−0.21			−0.31			−0.44	
Volume flexibility	1.32		0.76	0.76		0.14	0.31		−0.36	−0.29		−0.75	−1.03		−1.23
Investment flexibility															
Buildings	−0.38		−0.41	−0.02		−0.26	0.27		−0.14	0.47		0.18	0.73		0.58
Machinery															
Workforce	−0.67			−0.20			0.18			0.75			1.47		
Panel B: Using GMM coefficient estimates															
Production flexibility															
Process flexibility		0.56	0.87		0.09	0.24		−0.28	−0.27		−0.45	−0.61		−0.67	−1.04
Product flexibility	1.44	0.28		0.73	0.06		0.16	−0.11		−0.50	−0.21		−1.33	−0.34	
Volume flexibility	1.87		1.13	0.96		0.29	0.24		−0.38	−0.64		−0.81	−1.74		−1.36
Investment flexibility															
Buildings	−0.27		−0.33	−0.01		−0.27	0.19		−0.23	0.37		0.19	0.59		0.73
Machinery	−0.21	−0.19		−0.05	−0.12		0.08	−0.07		0.25	0.15		0.46	0.42	
Workforce	−0.52		−0.48	−0.11		−0.35	0.22		−0.25	0.63		0.33	1.14		1.06

Shown are predicted percentage changes in the financial structure ratios using OLS and GMM coefficient estimates and regressor means as the real flexibility proxies vary from the 5th to 95th percentiles. Reported in each row are predicted percentage changes relative to the sample mean, normalized by the sample range, for each dependent variable holding all regressors except for the relevant flexibility proxy at their sample mean levels. The dependent variables are financial leverage (total debt divided by total assets, TD/TA), maturity structure (long-term debt divided by total debt, LD/TD), and credit structure (public debt divided by total debt, PD/TD). Elasticities of input and output substitution proxy for process and product flexibility. The absolute value of the log elasticity of cash flow to production level proxies for volume flexibility. The absolute value of the log ratio of the actual and shadow rents of capital proxies for investment flexibility (used for buildings, machinery, and workforce flexibility). Operating leverage is fixed-capital (buildings and machinery) divided by total labor costs (wages, salaries, and benefits). Cash flow volatility is the standard deviation of cash flow divided by mean total assets (using up to 20 quarters). Diversification is one minus the Herfindahl of output of a firm's four-digit SIC industries. Values for statistically insignificant coefficients are omitted.

5.3 Firm size

The descriptive statistics presented in Table 1 show that small firms are generally more flexible than large firms. Table 1 also shows greater dispersion and cross-sectional variation among small firms than large firms. These facts suggest that the relations I find between real flexibility and financial structure in Table 3 for the entire sample should be sharper (dimmer) among small (large) firms.

One might expect real flexibility to benefit small firms more than large firms, as small firms are less diversified and lack the access large firms have to financial markets. Therefore real flexibility could prove critical to small firms in averting financial distress and supporting their financial policy. One could also argue that size is a proxy for the severity of the agency conflicts that oppose firm claimants. Small firms, with high-powered managers, concentrated equity ownership, and many real options, are liable to risk shift, resulting in acute shareholder–debt-holder conflicts and high agency costs. Large firms, with risk-averse managers, dispersed equity ownership, and few real options, are perhaps less likely to use real flexibility to the detriment of debt-holders. For all these reasons, support for the value and agency hypotheses should be sharper among small firms.

Table 5 shows that the relations I find between real flexibility and financial structure in the entire sample are primarily driven by large firms, not by small firms, as hypothesized. Indeed, results for the large-firm sample in Table 5 are very similar to those presented in Table 3 for the entire sample. One exception is the positive relation between financial leverage and workforce flexibility, which is unique to the small-firm sample. Among large firms, workforce flexibility is actually inversely related to debt maturity, a finding which does not obtain for small firms nor the entire sample, and goes against the general conclusion that investment flexibility supports financial policy.

Although financial leverage is positively related to machinery flexibility among large firms, this relation reverses among small firms. This suggests that, unlike large firms with reputation capital at stake, lenders believe that small firms might substitute their flexible machinery assets for riskier assets or managerial perks. The monitoring effort needed to prevent such substitution might be too costly to bear for small firms but not for large firms, possibly explaining the split in results.

5.4 Real and financial flexibility: substitutes or complements?

A long-standing question in corporate finance is whether real risk and financial risk are directly or inversely related. A variant of that question is whether real flexibility and financial flexibility are substitutes or complements. Mauer and Triantis (1994) address this question by modeling the time dynamics of financial structure when both reorganization and recapitalization are costly. They show that real and financial flexibility are

Table 5
GMM regressions of financial-structure ratios on real flexibility by firm size

	Small firms			Large firms		
Dependent variables:	TD/TA	LD/TD	PD/TD	TD/TA	LD/TD	PD/TD
Financial structure						
Total debt/total assets		0.15***	−0.12***		0.32***	−0.54***
		(0.03)	(0.03)		(0.03)	(0.04)
Long-term debt/total debt	0.06***		0.35***	0.14***		0.33***
	(0.01)		(0.02)	(0.01)		(0.02)
Public debt/total debt	−0.03***	0.21***		−0.12***	0.16***	
	(0.01)	(0.01)		(0.01)	(0.02)	
Production flexibility						
Process flexibility	−0.02	−0.07	−0.03	−0.05**	−0.01	−0.11**
	(0.02)	(0.05)	(0.39)	(0.02)	(0.06)	(0.05)
Product flexibility	−0.02*	−0.09	−0.01*	−0.01*	−0.02*	−0.02**
	(0.01)	(0.08)	(0.02)	(0.00)	(0.01)	(0.01)
Volume flexibility	−0.02*	−0.02	−0.01	−0.03***	0.04	−0.09***
	(0.01)	(0.12)	(0.01)	(0.01)	(0.13)	(0.01)
Investment flexibility						
Buildings	−0.04	−0.05	0.34**	0.36***	−0.15	0.27***
	(0.09)	(0.16)	(0.15)	(0.05)	(0.13)	(0.10)
Machinery	−0.10**	0.30*	−0.27	0.26	0.26	−0.26
	(0.04)	(0.18)	(0.25)	(0.12)	(0.15)	(0.18)
Workforce	0.25***	0.18	0.32*	−0.02	−0.35***	0.36**
	(0.09)	(0.13)	(0.18)	(0.06)	(0.11)	(0.15)
Control variables						
Risk						
Operating leverage	0.00	0.00	−0.01**	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Cash flow volatility	0.22***	−0.51***	0.36***	0.62***	−0.41***	−0.11
	(0.05)	(0.07)	(0.07)	(0.04)	(0.1)	(0.1)
Profitability						
Cash flow/total assets	−0.34***	0.29***	0.16**	−0.52***	0.63***	0.07
	(0.04)	(0.07)	(0.08)	(0.04)	(0.07)	(0.08)
Diversification						
1-Output Herfindahl	0.05**	0.06	−0.06	0.05***	−0.10***	0.19***
	(0.02)	(0.04)	(0.05)	(0.01)	(0.02)	(0.02)
Size (log of total assets)	0.03***	0.06***	0.02***	0.02***	0.04***	0.03***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Wald statistic	998***	1052***	461***	1667***	653***	568***
Degrees of freedom	1219	1219	1219	2113	2113	2113
Hansen's *J*-statistic (16 dof)	405***	363***	369***	170***	213***	255***

Small- and large-firm GMM regressions of the financial structure ratios on the real flexibility indicators, control variables, and industry and year dummies. The variables are first-differenced to control for firm fixed effects and instrumented by the second and third lagged levels of all variables. Firm size is relative to the sample median output level. The dependent variables are financial leverage (total debt divided by total assets, TD/TA), maturity structure (long-term debt divided by total debt, LD/TD), and credit structure (public debt divided by total debt, PD/TD). Elasticities of input and output substitution proxy for process and product flexibility. The absolute value of the log elasticity of cash flow to production level proxies for volume flexibility. The absolute value of the log ratio of the actual and shadow rents of capital proxies for investment flexibility (used for buildings, machinery, and workforce flexibility). Operating leverage is fixed capital (buildings and machinery) divided by total labor costs (wages, salaries, and benefits). Cash flow volatility is the standard deviation of cash flow divided by mean total assets (using up to 20 quarters). Diversification is one minus the Herfindahl of output of a firm's four-digit SIC industries. The Newey–West procedure is used to correct for heteroscedasticity and MA (1) autocorrelation introduced by first-differencing. Asymptotic standard errors in parentheses.

***,**,* denote statistical significance at the 1%, 5%, and 10% levels, respectively.

substitutes in terms of their effect on the value of the debt tax shield. To test this prediction, I regress the time ranges of firms' financial structure ratios (maximum minus minimum between 1977 and 1990) on their mean real flexibility levels for the same period. I use these financial structure time ranges as proxies for financial flexibility, with a wide time range pointing to high recapitalization costs, or low financial flexibility.

Table 6 reports heteroscedastic-consistent OLS and two-limit Tobit estimates for these regressions. Unlike the within-firm regressions presented in Table 3, where censoring had no material impact on the findings, the Tobit results in the right-hand panel of Table 6 suggest that the OLS coefficient estimates and standard errors in these between-firm regressions are biased because of censoring.

Consistent with the Mauer and Triantis (1994) prediction that real and financial flexibility are substitutes, I find evidence of a positive relation between the financial structure ratio time ranges and the average real flexibility levels. Specifically, all but one of the real flexibility coefficients in Table 6 are positive, though only buildings and workforce flexibility are significant under Tobit. These results suggest that the ability to adjust real capacity is a substitute for financial flexibility.

6. Conclusion

This article examines the empirical relation between real flexibility and financial structure. I formulate and test two competing hypotheses. The value hypothesis holds that by expanding the range of conditions under which a firm can profitably operate, real flexibility increases debt capacity by lowering default risk and enhancing the collateral value of assets. The agency hypothesis holds that real flexibility decreases debt capacity by broadening the scope for opportunism.

I find that financial leverage, debt maturity, and public debt are negatively related to production flexibility but positively related to investment flexibility. This split in results across production and investment flexibility proxies suggests that the value and agency hypotheses are both operative. Production flexibility reflects areas where firms have managerial discretion and cannot commit against risk shifting. This decreases debt capacity. Investment flexibility reflects areas where firms have managerial discretion but can commit against asset substitution. This increases debt capacity.

Beyond statistical significance, real flexibility has a material economic effect on financial structure. For instance, as volume flexibility rises from the 5^{th} to 95^{th} percentile, predicted total debt over total assets decreases 3.61% and predicted public debt over total debt decreases 2.49%. Although one might expect real flexibility to accentuate the value and agency hypotheses among small firms, the relations I find between

Table 6
OLS and Tobit regressions of financial structure time ranges on real flexibility levels

	OLS			Two-limit Tobit		
Dependent variables:	TD/TA	LD/TD	PD/TD	TD/TA	LD/TD	PD/TD
Production flexibility						
Process flexibility	−0.01	0.09	0.11	−0.03	0.12	0.14
	(0.05)	(0.10)	(0.12)	(0.10)	(0.18)	(0.25)
Product flexibility	0.01	0.01	0.01	0.02	0.02	0.03
	(0.01)	(0.03)	(0.03)	(0.03)	(0.06)	(0.08)
Volume flexibility	0.05	0.09	0.25	0.18	0.37	0.63*
	(0.07)	(0.14)	(0.17)	(0.13)	(0.27)	(0.37)
Investment flexibility						
Buildings	0.02*	0.02	0.02	0.05***	0.07**	0.08*
	(0.01)	(0.02)	(0.02)	(0.02)	(0.03)	(0.05)
Machinery	0.01	0.00	0.02	0.00	0.00	0.04
	(0.01)	(0.02)	(0.02)	(0.02)	(0.03)	(0.05)
Workforce	0.02***	0.03**	0.04**	0.05***	0.09**	0.11***
	(0.01)	(0.01)	(0.02)	(0.01)	(0.03)	(0.04)
Control variables						
Risk						
Operating leverage	0.02	−0.02	−0.01	0.01	−0.04	−0.02
	(0.01)	(0.03)	(0.03)	(0.03)	(0.05)	(0.07)
Cash flow volatility	0.03	0.24**	−0.01	0.05	0.32	−0.02
	(0.05)	(0.10)	(0.01)	(0.09)	(0.18)	(0.25)
Profitability						
Cash flow/total assets	0.09**	0.20***	0.30***	0.23***	0.49***	0.65***
	(0.04)	(0.07)	(0.09)	(0.07)	(0.14)	(0.19)
Diversification						
1–Output Herfindahl	0.01	0.02	0.06*	0.05**	0.09*	0.18**
	(0.01)	(0.03)	(0.03)	(0.03)	(0.05)	(0.07)
Size (log of total assets)	0.01***	0.02***	0.02***	0.02***	0.05***	0.05***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.01)
Adjusted R^2/log-likelihood	3.1%	3.3%	3.2%	−226	−851	−1124
DOF/noncensored observations	1523	1523	1523	858	824	659

OLS and Tobit regressions of the firm-specific financial-structure time ranges (maximum–minimum for the sample period) on the firm-specific mean levels of the real flexibility indicators and the control variables. Industry dummies also included. The dependent variables are financial leverage (total debt divided by total assets, TD/TA), maturity structure (long-term debt divided by total debt, LD/TD), and credit structure (public debt divided by total debt, PD/TD). Elasticities of input and output substitution proxy for process and product flexibility. The absolute value of the log elasticity of cash flow to production level proxies for volume flexibility. The absolute value of the log ratio of the actual and shadow rents of capital proxies for investment flexibility (used for buildings, machinery, and workforce flexibility). Operating leverage is fixed capital (buildings and machinery) divided by total labor costs (wages, salaries, and benefits). Cash flow volatility is the standard deviation of cash flow divided by mean total assets (using up to 20 quarters). Diversification is one minus the Herfindahl of output of a firm's four-digit SIC industries. Heteroscedastic-consistent standard errors in parentheses.

***,**,* denote statistical significance at the 1%, 5%, and 10% levels, respectively.

financial structure and real flexibility are concentrated among large firms. Lastly, I find that real and financial flexibility are substitutes, as Mauer and Triantis (1994) predict.

Although I take these findings at face value, the reader should keep in mind that my results are only as reliable as the methods I use to derive and estimate the real flexibility proxies. Limitations of the production and investment theory on which I base these methods carry over to this study. The proxies I develop for real flexibility capture some, but not all, of the real options firms carry. Also, though my GMM estimates address many econometric issues, the approach is reduced form rather than structural. Thus while this study tests whether real flexibility conditions financial structure, what determines the joint technology finance decision as modeled by Dammon and Senbet (1988), Maksimovic and Zechner (1991), and Williams (1995) remains an open empirical question.

Appendix A: Optimizing Framework and Econometric Implementation

This appendix contains the complete analytic derivation of the optimization framework and details of the econometric implementation. I assume a stochastic price-taking economic environment where firms solve two simultaneous optimization problems: (1) short-run (static) production decisions, and (2) long-run (dynamic) investment decisions.

A.1 Production decisions

The short-run (static) problem is to choose a production plan that maximizes expected period-t pretax cash flow:

$$\Pi(\mathbf{v} \mid \mathbf{p}, \dot{\mathbf{k}}, \mathbf{k}, \beta, \Omega_t) \equiv \max_{\mathbf{v}} E_t[\mathbf{p} \cdot \mathbf{v}(\mathbf{p}) \mid \mathbf{p}_{\tau<t}, \phi_t] \quad \text{subject to } \mathbf{v} \in \mathbf{V}(\dot{\mathbf{k}}, \mathbf{k}), \quad \mathbf{p} \in \mathbf{P}, \tag{A1}$$

where

$E_t[\cdot]$ = the conditional expectations operator, given information available at time t, Ω_t

ϕ_t = a vector of exogenous random determinants of demand, $Q = D(t, \mathbf{p}_t, \boldsymbol{\phi}_t)$

$\mathbf{v}$ = an n-vector of variable netputs: output (input) in positive (negative) net supply

$\mathbf{p}$ = an n-vector of exogenous (price-taking) random relative netputs prices (see Section A.5)

$\mathbf{P}$ = a nonempty conical compact set of prices defined over $\Re^n_{++}$ (the price space)

$\mathbf{k}$ = an m-vector of lagged quasi-fixed capacity inputs (physical and human capital stocks)

$\dot{\mathbf{k}}$ = an m-vector of time derivatives of $\mathbf{k}$ (net capacity adjustments): $\dot{\mathbf{k}} \equiv d\mathbf{k}/dt = \mathbf{i} - \delta \odot \mathbf{k}$

$\odot$ = is the Hadamard product operator, indicating element-by-element multiplication

$\mathbf{i}$ = an m-vector of gross capacity adjustments (expansion and contraction): $\mathbf{i} \in \mathbf{I}(\mathbf{k})$

$\mathbf{I}(\mathbf{k})$ = a convex set of investment possibilities defined over $\Re^m$, given $\mathbf{k}$

δ = an m-vector of exogenous capacity attrition rates, that is, depreciation of physical capital and voluntary workforce turnover (Hamermesh and Pfann, 1996)

$\mathbf{V}(\dot{\mathbf{k}}, \mathbf{k})$ = a convex set of production possibilities defined over $\Re^n$, given $\mathbf{k}$ and $\dot{\mathbf{k}}$

β = a vector of technology coefficients for the specified objective function, $\Pi(\cdot)$ (see Section A.3)

$\mathbf{r}$ = an m-vector of market rental rates for the service flow of capacity inputs: $\mathbf{r} = \kappa \odot (\rho + \delta)$

κ = an m-vector of relative prices of capacity inputs

ρ = an m-vector of real interest rates for Aaa-bonds plus a firm-specific risk premium (see Section A.4)

Netput supply equations follow from the envelope theorem:

$$\frac{\partial \Pi(\mathbf{v}\,|\,\mathbf{p},\,\dot{\mathbf{k}},\,\mathbf{k},\,\Omega_t)}{\partial \mathbf{p}} = \mathbf{v}^*. \tag{A2}$$

Consistent with available data, I assume that firms' production decisions, $\mathbf{v}$, consist in choosing the levels of two output products, Y and Z (a primary and secondary product), and two input factors, L and P (labor and materials), conditional on their capacity inputs in place ($\mathbf{k}$) and their capacity input adjustments ($\dot{\mathbf{k}}$). The capacity inputs are buildings (B), machinery (M), and workforce (W). Following Whited (1992), I lag these capacity inputs to reflect time to build. Capacity adjustments refer to net changes in these capital stocks ($\dot{\mathbf{k}} = \mathbf{i} - \delta \odot \mathbf{k}$) where $\mathbf{i}$ is gross annual investment (or divestment) in buildings ($\dot{B} \approx \Delta B$), machinery ($\dot{M} \approx \Delta M$), and workforce ($\dot{W} \approx \Delta W$), and δ denotes capacity attrition rates, that is, depreciation of physical capital (buildings and machinery), and workforce quit rates (assumed zero for lack of data). All variables are deflated to 1972 dollar levels. Input and output deflators (four-digit SIC) are from the NBER, physical-capital deflators and depreciation rates (two-digit SIC) are from the BEA.

Given the annual frequency of the data, I further assume that $\mathbf{v}$ is set at the beginning of each year and cannot be revised until the end of the year, when prices and demand are realized. Thus, following the rational expectations approach of Pindyck and Rotemberg (1983), I assume firms choose $\mathbf{v}$ on the basis of conditional expected prices and demand, $\bar{\mathbf{p}}_t = E_t[\mathbf{p}\,|\,\mathbf{p}_{\tau<t}]$ and $\bar{\boldsymbol{Q}}_t = (\boldsymbol{t}, \bar{\mathbf{p}}_{\boldsymbol{t}}, \boldsymbol{\phi}_t)$, rather than ex post realized prices and demand. I estimate conditional expected prices using vector autoregressions (as explained in Section A.4).

A.2 Investment decisions

The long-run (dynamic) problem is to pick an investment path to maximize the expected present value of cash flow:

$$\max_{\{\dot{\mathbf{k}}_\tau\}_{\tau=t}^{\infty}} \int_t^\infty e^{-\rho\tau}[\Pi(\mathbf{v}\,|\,\mathbf{p},\,\dot{\mathbf{k}},\,\mathbf{k},\,\Omega_t) - \mathbf{r}\cdot\mathbf{k}]d\tau = \max_{\{\dot{\mathbf{k}}_\tau\}_{\tau=t}^{\infty}} \int_t^\infty F(\tau,\,\mathbf{v},\,\mathbf{p},\,\dot{\mathbf{k}},\,\mathbf{k},\,\Omega_t)d\tau \tag{A3}$$

subject to $\mathbf{k}(\tau = t) = \mathbf{k}_t$ (initial conditions), $\mathbf{k}(\tau \to \infty) \in \mathbf{K}$ (terminal conditions), and $\mathbf{r} = \kappa \odot (\rho + \delta)$.

Solving this calculus of variations problem, the first-order conditions are m simultaneous Euler equations:

$$F_{\mathbf{k}} - \frac{dF_{\dot{\mathbf{k}}}}{dt} = \mathbf{0}_m \;=\; F_{\mathbf{k}} - (F_{\dot{\mathbf{k}}t} + F_{\dot{\mathbf{k}}\mathbf{k}}\dot{\mathbf{k}} + F_{\dot{\mathbf{k}}\dot{\mathbf{k}}}\ddot{\mathbf{k}}) \tag{A4}$$

$$\mathbf{0}_m \;=\; e^{-\rho\tau}\left[\Pi_{\mathbf{k}} - \mathbf{r} - (\Pi_{\dot{\mathbf{k}}\mathbf{k}}\dot{\mathbf{k}} + \Pi_{\dot{\mathbf{k}}\dot{\mathbf{k}}}\ddot{\mathbf{k}} - \rho\Pi_{\dot{\mathbf{k}}})\right] \tag{A5}$$

$$\Pi_{\mathbf{k}} - \mathbf{r} \;=\; \Pi_{\dot{\mathbf{k}}\mathbf{k}}\dot{\mathbf{k}} + \Pi_{\dot{\mathbf{k}}\dot{\mathbf{k}}}\ddot{\mathbf{k}} - \rho\Pi_{\dot{\mathbf{k}}}. \tag{A6}$$

A.3 Econometric implementation

The chosen functional form is a symmetric generalized McFadden (SGM) adapted from Diewert and Wales (1987):

$$\begin{aligned}
\Pi(\mathbf{v}\,|\,Q, t,\,\mathbf{p},\,\dot{\mathbf{k}},\,\mathbf{k}) = {} & g(\mathbf{p})Q + \sum_h^n \alpha_h p_h + t\sum_h^n p_h\left[\beta_{ht} + \sum_i^m \beta_{hti}\dot{k}_i + \sum_j^m \beta_{htj}k_j\right] \\
& + \sum_h^n p_h\left[\sum_i^m \chi_{hi}\dot{k}_i + \frac{1}{2}\sum_i^m\sum_j^m \chi_{hij}\dot{k}_i\dot{k}_j + \sum_i^m \phi_{hi}k_i + \frac{1}{2}\sum_i^m\sum_j^m \phi_{hij}k_ik_j\right. \\
& \left. + \frac{1}{2}\sum_i^m\sum_j^m \lambda_{hij}\dot{k}_ik_j\right] + Q\sum_h^n p_h\left[\delta_h + \delta_{ht}t + \sum_i^m \delta_{hi}\dot{k}_i + \sum_j^m \delta_{hj}k_j\right] \\
& + Q^2\sum_h^n p_h\left[\gamma_h + \gamma_{ht}t + \sum_i^m \gamma_{hi}\dot{k}_i + \sum_j^m \gamma_{hj}k_j\right]
\end{aligned} \tag{A7}$$

where

$$g(\mathbf{p}) = \frac{1}{2}\left[\frac{\mathbf{p}'\mathbf{S}\mathbf{p}}{\theta \cdot \mathbf{p}}\right] \quad h \in \{Y, Z, L, P\} \quad i \in \{\dot{B}, \dot{M}, \dot{W}\} \quad j \in \{B, M, W\} \tag{A8}$$

and t is the vintage (age) of a plant's capital stock.

θ is a n-vector of nonnegative netput price weights not all zero ($\theta \gg 0$). $\mathbf{S}$ is an $n \times n$ symmetric negative semidefinite (NSD) matrix such that $\mathbf{S} \cdot \mathbf{p}^* = \mathbf{0}_n$ for some $\mathbf{p}^* \gg 0$. The latter is an identification condition. $\Pi(\cdot)$ is linearly homogeneous in $\mathbf{p}$, and netput price convexity holds globally if $\mathbf{S}$ is NSD. This specification is very general, allowing for embodied technological change ($\exists h \,|\, \{\beta_{ht}, \beta_{hti}, \beta_{htj}, \delta_h, \gamma_h\} \gg 0$), nonlinear homogeneity in $Q(\exists h|\{\gamma_h,\gamma_{ht},\gamma_{hi},\gamma_{hj}\} \gg 0)$, nonhomotheticity ($\exists\ h \,|\, \{\delta_h, \delta_{ht}, \delta_{hi}, \delta_{hj}\} \gg 0$), internal capacity adjustment costs ($\exists h \,|\, \beta_{hti}, \chi_{hi}, \chi_{hij}, \lambda_{hij}, \delta_{hi}\gamma_{hi} \gg 0$), capacity constraints ($\exists h|\beta_{htj}, \phi_{hj}, \phi_{hij}, \lambda_{hij}, \delta_{hj}, \gamma_{hj}\} \gg 0$), and second-order functional form flexibility in the sense of Diewert (1974), that is, $2 + 9n + 8n^2$ free parameters at an arbitrary approximation point, $\{Q^*, t^*, \mathbf{p}^*, \dot{\mathbf{k}}, \mathbf{k}^*\}$.

The n first-order conditions corresponding to the netput supply equations [Equation (A2)] are

$$\begin{aligned}\frac{\partial \Pi(\mathbf{v} \,|\, Q, t, \mathbf{p}, \dot{\mathbf{k}}, \mathbf{k})}{\partial p_h} = \nu_h^* &= g_h(\mathbf{p})Q + \alpha_h + t\left[\beta_{ht} + \sum_i^m \beta_{hti}\dot{k}_i + \sum_j^m \beta_{htj}k_j\right] \\ &+ \left[\sum_i^m \chi_{hi}\dot{k}_i + \frac{1}{2}\sum_i^m\sum_j^m \chi_{hij}\dot{k}_i\dot{k}_j + \sum_i^m \phi_{hi}k_i + \frac{1}{2}\sum_i^m\sum_j^m \phi_{hij}k_ik_j \right. \\ &+ \left. \frac{1}{2}\sum_i^m\sum_j^m \lambda_{hij}\dot{k}_ik_j\right] + Q\left[\delta_h + \delta_{ht}t + \sum_i^m \delta_{hi}\dot{k}_i + \sum_j^m \delta_{hj}k_j\right] \\ &+ Q^2\left[\gamma_h + \gamma_{ht}t + \sum_i^m \gamma_{hi}\dot{k}_i + \sum_j^m \gamma_{hj}k_j\right] \quad h \in \{Y, Z, L, P\}.\end{aligned} \tag{A9}$$

The m first-order conditions corresponding to the Euler equations in Equation (A6) are

$$\begin{aligned}&\sum_h^n p_h\left[t\beta_{htj} + \phi_{hi} + \frac{1}{2}\sum_i^m \phi_{hij}k_i + \frac{1}{2}\sum_i^m \lambda_{hij}\dot{k}_i + Q\delta_{hj} + Q^2\gamma_{hj}\right] - r_j \\ &\quad = \frac{1}{2}\sum_h^n p_h\lambda_{hij}\dot{k}_i - \rho_j\sum_h^n p_h\left[t\beta_{hti} + \chi_{hi} + \frac{1}{2}\sum_i^m \chi_{hij}\dot{k}_i + \frac{1}{2}\sum_j^m \lambda_{hij}k_j + Q\delta_{hi} + Q^2\gamma_{hi}\right] \\ &\qquad i \in \{\dot{B}, \dot{M}, \dot{W}\}.\end{aligned} \tag{A10}$$

An additive disturbance term is added to each of the n netput supply equations and m Euler equations. To address the endogeneity of the production level (Q), I also include a demand function of the form $Q = D(t, \mathbf{p}, \phi)$, where ϕ is a vector of exogenous determinants of demand (industry-level output, price, and output volatilities). Since these equations share common coefficients and their residuals are interdependent, the system is estimated simultaneously by iterated GMMs using levels and interactions of the lagged variables as instruments. The model is estimated on plant-level data, by industry for the period 1972 to 1990. Restrictions are imposed after the first iteration to obtain curvature conditions in compliance with microeconomic theory. Diewert and Wales (1987) show that netput price convexity holds globally if $\mathbf{S}$ is NSD. Therein lies the main theoretical appeal of the SGM functional form. In practice, these curvature restrictions proved too constraining to achieve estimation convergence and had to be lifted, resulting in local violations of the curvature requirements.

A.4 Estimating firm-specific risk-adjusted real discount rates

I estimate firm-specific risk-adjusted real discount rates as follows. Using all firms available on S&P's COMPUSTAT between 1985 (when S&P credit scores become available) and 1990 (when the LRD sample ends), I collect S&P credit scores (data item 280), as well as firm characteristics for which a close equivalent exists in the LRD sample, namely, net plant and equipment (LRD-equivalent: building and machinery stocks) and total number of employees (also available in the LRD). I regress the S&P credit scores on net plant and equipment, total number of employees, and the squared values of these two variables. Although parsimonious, this specification yields an adjusted R^2 of 53%, with reasonable coefficients and predicted values. I then apply the estimated model to the LRD sample to produce fitted credit scores for each firm-year. I divide each fitted score by the median fitted score (roughly equivalent to a score of 11 or a Moody's Baa rating) to generate a firm-specific risk indicator. I divide fitted scores by the median rather than by the full sample range because of limited bond yield availability (Moody's Baa being the riskiest rating for which I could find bond-yield indices). This truncated scaling yields risk-indicator values greater than one and allows for fitted risk scores worse than a Baa rating. I collect average yields for bonds rated Aaa and Baa between 1972 and 1990 (the life span of the LRD sample) and produce firm-specific risk-adjusted discount rates by multiplying the value of the firm's fitted risk indicator by the Baa-Aaa risk premium and adding this product to the Aaa yield. I use four-digit SIC NBER price deflators to remove inflation and obtain real discount rates.

A.5 Estimating conditional expected prices

Predicted prices serve as proxies for conditional expected input and output prices, as follows. Using four-digit SIC input and output price series from the NBER, I run rolling 14-year trend-stationary twice-lagged vector auto regressions (VAR[2]) on the levels of the four price indices for each industry and each year between 1972 and 1990. The choice of a 14-year window and 2-year lags was dictated by the annual frequency of available data, which begins in 1958.

$$\begin{aligned}
p_{Yt} =&\ \alpha_Y + \beta_Y t + \phi_{YY_1} p_{Y_{t-1}} + \phi_{YY_2} p_{Y_{t-2}} + \phi_{YZ_1} p_{Z_{t-1}} + \ldots + \phi_{YL_2} p_{L_{t-2}} + \phi_{YP_1} p_{P_{t-1}} \\
&+ \phi_{YP_2} p_{P_{t-2}} + u_{Yt} \\
p_{Zt} =&\ \alpha_Z + \beta_Z t + \phi_{ZY_1} p_{Y_{t-1}} + \phi_{ZY_2} p_{Y_{t-2}} + \phi_{ZZ_1} p_{Z_{t-1}} + \ldots + \phi_{ZL_2} p_{L_{t-2}} + \phi_{ZP_1} p_{P_{t-1}} \\
&+ \phi_{ZP_2} p_{P_{t-2}} + u_{Zt} \\
p_{Lt} =&\ \alpha_L + \beta_L t + \phi_{LY_1} p_{Y_{t-1}} + \phi_{LY_2} p_{Y_{t-2}} + \phi_{LZ_1} p_{Z_{t-1}} + \ldots + \phi_{LL_2} p_{L_{t-2}} + \phi_{LP_1} p_{P_{t-1}} \\
&+ \phi_{LP_2} p_{P_{t-2}} + u_{Lt} \\
p_{Pt} =&\ alpha_P + \beta_P t + \phi_{PY_1} p_{Y_{t-1}} + \phi_{PY_2} p_{Y_{t-2}} + \phi_{PZ_1} p_{Z_{t-1}} + \ldots + \phi_{PL_2} p_{L_{t-2}} + \phi_{PP_1} p_{P_{t-1}} \\
&+ \phi_{PP_2} p_{P_{t-2}} + u_{Pt}
\end{aligned}$$

In vector notation,

$$\mathbf{p}_t \ = \ \boldsymbol{\psi}\mathbf{X}_t + \mathbf{u}_t \ = \ [\boldsymbol{\alpha} \quad \boldsymbol{\beta} \quad \boldsymbol{\Phi}_1 \quad \boldsymbol{\Phi}_2] \cdot \begin{bmatrix} 1 \\ \mathbf{t} \\ \mathbf{p}_{t-1} \\ \mathbf{p}_{t-2} \end{bmatrix} + \mathbf{u}_t \quad \text{with } \mathbf{u}_t \sim \text{i.i.d. } N(\mathbf{0}, \boldsymbol{\Sigma}_t) \tag{A5}$$

Consequently prices are assumed to be conditionally distributed as

$$\mathbf{p}_t \mid \{\mathbf{t}, \mathbf{p}_{t-1}, \mathbf{p}_{t-2}\} \sim N(\boldsymbol{\psi}\mathbf{X}_t, \boldsymbol{\Sigma}_t) \quad \text{with } \hat{\boldsymbol{\Sigma}}_t \ = \ E[\hat{\mathbf{u}}_t \hat{\mathbf{u}}_t'].$$

This system of four equations is fit using iterated seemingly unrelated regressions, one for each year and industry. Predicted prices ($\hat{\mathbf{X}}_t$) proxy for conditional expected prices ($\bar{\mathbf{p}}_t \ = \ E_t[\mathbf{p} \mid \mathbf{p}_{\tau<t}]$) in the profit function estimation.

Appendix B: Manufacturing Industries Retained in the Study

The selection criteria described in Section 3.2 produced the set of industries shown in Table

SIC	Abbreviation	Full description
2011	Meat Processing	Fresh and Frozen Meat from Animals Slaughtered in this Plant
2221	Weaving Mills	Weaving Mills, Manmade Fiber and Silk
2339	Outerwear	Women's and Misses Outerwear
2421	Sawmills	Sawmills and Planning Mills
2511	Furniture	Wood Household Furniture
2711	Newspapers	Newspapers
2851	Paints	Paints and Allied Products
2911	Petroleum Products	Petroleum Products
3079	Plastic Products	Miscellaneous Plastic Products
3143	Footwear	Men's Footwear, Except Athletic
3241	Cement	Hydraulic Cement
3312	Steel Mills	Blast Furnaces and Steel Mills
3441	Metal Products	Fabricated Structural Metal
3573	Computers	Computer and Office Equipment
3662	Radio & TV	Radio and TV Communication Equipment
3714	Auto Parts	Motor Vehicle parts and Accessories
3825	Instruments	Instruments to Measure Electricity
3911	Jewelry	Jewelry, Precious Metals

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