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Abstract
This paper presents a dynamic investment model that explains differences in the sensitivity of small- and large-sized firms to changes in the money market interest rate. In contrast to existing studies on the firm size effects of monetary policy, the importance of firms as monetary transmission channel does not originate from credit market imperfections, but from size-related differences in the degree of investment irreversibility. The degree of investment irreversibility is determined by sunk capital investment expenditures. We show that size-related differences in sunk investment expenditures have two interdependent effects: they (i) affect the optimal investment behavior of small- and large-sized firms and (ii) account for differences in the interest rate sensitivity of small- and large-firm investment. We illustrate that sunk investment expenditures affect the region of zero and non-zero investment activity and, hence, the frequency at which large and small firms change investment regimes. Furthermore, sunk investment costs determine the extent to which small- and large-firm investment displays discrete jumps. We find that large firms change investment regimes less frequently than small firms and that swings in investment are more accentuated for large than for small firms. We illustrate that the response of small- and large-firm investment to monetary policy actions depends on the magnitude of the monetary policy shock.

Keywords: Monetary Policy Transmission, Market Structure, Investment, Investment Irreversibility

JEL classification: E22, E52, L22

1 Introduction

Existing theoretical and empirical work links the effectiveness of monetary policy actions to the size distribution of firms. Common to these studies is that they view firm size as a proxy variable of the credit channel. According to the credit channel theory, credit market imperfections and financing constraints arising from information asymmetries amplify the effects of monetary policy. Because asymmetric information problems are viewed to be more severe for small than for large firms, small firms are typically considered to be more affected by monetary policy actions. Monetary policy effectiveness is, thus, assumed to increase with the proportion of small firms in an economy. However, empirical evidence on the firm size effects of monetary policy provides ambiguous support for this relationship. Gertler and Gilchrist (1994), Oliner and Rudebusch (1996), Ganley and Salmon (1997), De Bondt (2000), Dedola and Lippi (2000), and Ehrmann (2005), among others, find small firms to be relatively more sensitive to interest rate shocks than large firms. Evidence against firm size effects is reported by, for example, Carlino and DeFina (1998, 1999a, 1999b, 2000), Mojon, Smets, and Vermeulen (2002), and Arnold and Vrugt (2004).

The ambiguity of the empirical results suggests that firm size effects of monetary policy are not exclusively driven by information asymmetries and credit constraints. Motivated by this finding, the present paper does not not attribute possible firm size effects of monetary policy to credit market imperfections. Instead, we stress differences in the investment behavior of small and large firms as an alternative channel through which firm size may transmit monetary policy actions. At the core of this 'investment' channel are size-related differences in the degree of investment irreversibility.[1]

This paper assumes the existence of dual market structures to show that size-related differences in optimal investment behavior account for differences in the sensitivity of small and large firms to monetary policy actions. To this end, we present a theoretical investment model that links the investment behavior of small and large firms to the level of sunk investment expenditures and, hence, to the degree of investment irreversibility. One may argue that the assumption of a dual market structure is overly restrictive, limiting the applicability of the theoretical model. We will refute this concern and show that market dualization emphasizes and generalizes the main conclusions of the model because it stresses multiple sources of investment irreversibility

[1] Note, there is theoretical and empirical research on firm investment patterns for explicit adjustment cost functions or credit constraints (see, e.g., Bond and Meghir, 1994; Chatelain and Teurlai, 2004; Whited, 1992). However, the underlying evidence does not distinguish investment by firm size. Moreover, there is a large body of empirical evidence on the dynamic relations describing investment behavior of small and large firms (see, e.g., Angeloni, Kashyap, Mojon, and Terlizzese, 2003, for a compilation of studies.). However, investment patterns are not linked to sunk costs and typically assume the absence of irreversibility, uncertainty, delivery lags, and costs of capital adjustment.

as cause of size-related differences in optimal investment behavior. It will become evident that other types of market structure also feature differences in the optimal investment behavior of small and large firms and, hence, size-related asymmetries in the monetary policy response of investment. However, the size-related differences are less pronounced since alternative market structures only allow for single sources of investment irreversibility.

The paper proceeds as follows. Section 2 describes the process of market dualization and the characteristics of dual markets in terms of firm size distribution and investment behavior. We also review the existing literature on investment behavior in presence of adjustment costs and investment irreversibility. Section 3 develops the theoretical investment model that we use to discuss the 'investment' channel of monetary policy. We will show that firm size-related differences in sunk capital investment expenditures are an important source of differences in small- and large-firm investment behavior. Section 4 builds on the theoretical model and illustrates that size-related dissimilarities in sunk capital investment expenditures account for differences in the sensitivity of small- and large-firm investment to monetary policy shocks. Section 5 concludes.

2 Existing Literature

The discussion of the interest rate behavior of small- and large-firm investment assumes the coexistence of small and large firms in a dual market structure. This section starts out by reviewing theories of market dualization. In a next step, we discuss the principles of static and dynamic investment patterns and present studies which link firm size and investment behavior.

2.1 The Process of Market Dualization

The literature views dual market structures as the outcome of two different processes: scale economies and scope economies. Scale economies are at the core of Carroll's (1985) resource partitioning theory. He argues that dual market structures can evolve in industries characterized by scale economies and environmental resource heterogeneity. In this view, the market center is occupied by large firms that try to survive competitive pressures through scale economies. These firms produce generalized goods by exploiting a wide range of environmental resources. The market periphery is characterized by small specialized firms. These survive by using a narrow spectrum of environmental resources which differs from that exploited by large firms.

In that sense, small firms search for viable market niches through local product differentiation.[2]

Scope economies are at the core of Sutton's (1991, 1998) sunk cost theory. Since this theory underlies the subsequent theoretical model, we will assume that dual market structures are exclusively driven by scope rather than scale economies. Sutton (1991, 1998) explains the existence of dual market structures by stressing endogenous sunk costs resulting from irreversible investment in the field of, e.g., research and development (R&D).[3] Endogenous sunk costs differ from exogenous sunk costs in that production is augmented by but not dependent on the associated investment. Closely related, endogenous sunk costs are not necessarily paid by all firms in a market, while exogenous sunk costs are. Firms incur endogenous sunk costs to gain a competitive lead through scope economies which are realized through sunk investment in product differentiation. In being irreversible and driven by product differentiation rather than cost and price advantages, Sutton (1991, 1998) argues that endogenous sunk costs may result in investment escalation. Since investment escalation is only sustainable by a small number of large firms, endogenous sunk costs split the market into two quasi-independent sub-markets. At the center of the dual market are those firms that sustain the competitive escalation of endogenous sunk costs, offering largely generalized (standardized) products. These firms are large. The market periphery hosts small firms that cannot sustain the endogenous sunk cost expenses, but continue to serve small-scale market niches by offering customized goods. Because small and large firms produce different goods (customized vs. standardized), the degree of inter-segment competition is low. This suggest that the relative importance of endogenous sunk costs determines the structure of the underlying market and the presence of small and large firms across market segments.

2.2 Investment Behavior and Firm Size

This paper argues that differences in the sensitivity of small- and large-sized firms to monetary policy actions arise from the presence of sunk investment expenditures which influence the investment and, correspondingly, capacity choice of firms.[4] The literature views investment decisions as being the outcome of static or dynamic optimization problems. These differ in

[2]See also Boone and Van Witteloostuijn (1999) for a detailed description of the underlying theory and related criticism.

[3]Sutton (1991, 1998) also uses advertising outlays as example of endogenous sunk costs. For reason of tractability, we do not analyze the role of these expenses as a force behind market dualization.

[4]Note, sunk investment costs can also be seen as determinant of a firm's industry entry/exit decision. In contrast to sunk costs associated with capacity choice, sunk entry/exit costs are independent of firm size and determined at the industry level.

that they describe either the demand for the stock of capital or the demand for the flow of capital (investment). Jorgenson (1963) specifies a static model that describes the demand for the stock of capital as a function of the user cost of capital. The model generates a straightforward rule of optimal investment behavior which requires investment up to the point where the marginal revenue product of the stock of capital is equal to the real user cost. Empirical studies cast doubt on the reasonability of this neoclassical investment model. In assuming costless reversibility of investment and the absence of capital adjustment costs, it cannot account for the observed gradual response of investment to changes in economic conditions. Dynamic models describe the demand for the flow of investment. The dynamics arise from market distortions related to investment irreversibility, capital adjustment costs, and uncertainty.[5] These factors are interdependent and influence investment behavior by creating an option value of delaying investment until new information arrives. The underlying market frictions preclude the instantaneous adjustment of the capital stock to changes in economic conditions and may give rise to threshold investment behavior.[6]

Most studies on the investment effects of irreversibility abstain from establishing a direct link between firm size and investment behavior. An exception is Cabral (1995) who develops a game-theoretic model that stresses the relationship between sunk capacity costs (i.e., cost incurred in building production capacity), firm size, and firm growth. The model builds on the empirical regularity that small firms are more likely to exit an industry than large firms. Investment patterns of large and small firms are modeled in a two-period framework. In each period, optimal investment behavior is determined by the probability at which small and large firms exit the industry. Large firms are assumed to exit with low (or zero) probability in all periods. Their optimal choice therefore involves investment to the optimum long-run capacity level in all investment periods. Small firms, in contrast, exit with positive probability in period one, but stay with positive probability in period two. The relative ease at which small firms quit production in presence of sunk capacity costs causes them to invest less than the optimal long-run capacity level in period one. When small firms still operate in period two, they adjust capacity to the long-run level. The gradual investment, in turn, predicts small firms to grow faster than large firms. Although the theoretical model explains the negative relationship between firm size and firm growth, it does not allow for inferences as to the interest rate sensitivity of small- and large-sized firms.

[5] See, for example, Carruth, Dickerson, and Henley (2000), Lensink, Van Steen and Sterken (2005), Ninh, Hermes, and Lanjouw (2004) for surveys of theoretical and empirical investment models.

[6] See Abel and Eberly (1994, 1996, 1997), Barnett and Sakellaris (1998), Bloom, Bond, and Van Reenen (2001) for theoretical and empirical threshold investment studies.

On the empirical side, only Lensink, Van Steen, and Sterken (2000) and Ghosal and Loungani (2000) control for the possible relationship between firm size and firm investment and the role of firm size as determinant of the relationship between firm investment behavior and investment uncertainty. While Lensink, Van Steen, and Sterken (2000) explicitly distinguish the investment behavior of small and large firms, Ghosal and Loungani (2000) make a distinction between industries dominated by either small or large firms. Both studies assume that sunk investment expenditures and, hence, investment irreversibility increase with firm size.[7] Because sunk costs are an option value of waiting to invest, Lensink, Van Steen, and Sterken (2000) and Ghosal and Loungani (2000) expect the probability of a negative investment-uncertainty relationship to be higher for large than for small firms. A different relationship exists for financing constraints. Both studies argue that financing constraints increase the probability of a negative relationship between investment and uncertainty. Since financing constraints tend to be more pronounced for small rather than large firms, both studies expect the probability of a negative investment-uncertainty relationship to be higher for small than for large firms.

Ghosal and Loungani (2000) determine the investment-uncertainty relationship for a sample of Italian firms. Confirming theoretical predictions, the evidence from a panel analysis points to a negative relationship between investment and uncertainty. This relationship is stronger for industries which are dominated by small firms. Ghosal and Loungani (2000) conclude that the larger effect of uncertainty on investment for industries dominated by small firms points to the importance of financing constraints for small-firm investment, but not to the role of sunk costs. Lensink, Van Steen, and Sterken (2000) provide contrasting evidence. They employ survey data of Dutch firms to identify the investment-uncertainty relationship using a cross-section approach. The corresponding empirical results point to the existence of a positive investment-uncertainty relationship for small firms and to a negative relationship for large firms.

According to theoretical predictions, the observation that large firms reduce investment in response to higher uncertainty, whereas small firms increase investment points to the role of sunk costs as determinant of investment under uncertainty. In order to determine whether sunk costs are indeed a significant source of size-related differences in the investment-uncertainty relationship, Lensink, Van Steen, and Sterken (2000) test whether sunk costs and, hence, the degree of investment irreversibility increase with firm size. Descriptive evidence supports the

[7] Ghosal and Loungani (2000) derive the positive relationship between firm size and sunk costs indirectly from the observed negative impact of sunk costs on the degree of market entry (see Baumol, Panzer, and Willig, 1982; Tirole, 1989). Because sunk costs are a barrier to entry, they are concluded to lead to concentrated markets, consisting of large firms.

positive link. Measured as the share of investment in construction to total investment, sunk costs are larger for large than for small firms. Sunk costs, therefore, seem to increase the probability of a negative investment-uncertainty relationship. In order to assess the robustness of their results, Lensink, Van Steen, and Sterken (2000) also introduce financing constraints as mechanism which may influence the nature of the investment-uncertainty relationship for small and large firms. In contrast to Ghosal and Loungani (2000), descriptive statistics suggest that neither small nor large firms face a restricted capital market access and that financing constraints, hence, do not explain the observed investment-uncertainty relationship. Obviously, the evidence on the importance of sunk costs and financing constraints is indirect and needs to be interpreted with some caution.

Summarizing the literature on capital investment, capital adjustment is subject to real rigidities which result from investment irreversibility, where investment irreversibility is due to sunk investment costs. Even though sunk costs are argued to be positively related to firm size, existing studies do not explicitly model the relationship between sunk costs and firm size and the corresponding size-related effect of sunk costs on optimal investment behavior. Furthermore, theoretical and empirical studies are silent as to the effect of sunk costs on the sensitivity of small- and large-firm investment to changes in monetary policy. The remainder of this paper discusses these issues and asks whether size-related differences in sunk investment costs cause differences (i) in the optimal investment behavior of small and large firms and (ii) in the sensitivity of small- and large-firm investment to monetary policy changes? The following section presents the investment model which is used to answer these questions. Throughout this paper, we use the money market interest rate as proxy variable of the monetary policy stance.

3 A Model of Firm Investment

Although the q-approach (Tobin, 1969) is criticized on theoretical and empirical grounds[8], the present paper employs the q-approach to model the investment behavior of small and large firms. The main reason is that alternative investment models such as the Euler equation approach (Abel, 1980) or the Abel and Blanchard (1986) approach do not allow the specification of investment decision rules.[9].

[8]See Bond and Van Reenen (2003, chapter 3). The weaknesses are to some extent refuted by Erickson and Whited (2000).

[9]See Kalckreuth (2003) and Bond and Van Reenen (2003, chapter 3) for a description of these investment models.

Using the q-approach, the analysis is carried out for a discrete infinite time framework that allows for the partial irreversibility of investment. The discrete-time model builds on the continuous-time work by Abel and Eberly (1994, 1997). We extend the investment models by explicitly linking the investment decision of firms to the level of sunk costs associated with R&D. As we will show, the solutions to the optimal investment path allow for inferences regarding the interest rate sensitivity of small- and large-sized firms. A limitation of the study is that it does not discuss the options that firms have to finance investment projects, although these also affect the costs of finance. Instead, we assume that firms raise external funds at no other costs than the required interest rate. In assuming perfect credit markets, no attention is paid to the influence of financing constraints on firm investment, firm size, and firm size distribution.[10] Furthermore, the model does not specify the effect of taxation on investment and optimal investment behavior. Finally, in order to compare the investment decisions of small- and large-sized firms, the present analysis assumes that the structure of the optimization problem is the same for small and large businesses. The following sections define the production and investment cost function and develop the intertemporal value maximization problem of firms and the optimal solution.

3.1 Production Function

Our model assumes the existence of j=1, ..., M firms in a dual industry i. The assumption of a dual market structure is imposed to explicitly allow for the co-existence of small- and large-sized firms in an industry. Furthermore, it sets the stage for the discussion of the investment decision of large- and small-sized firms across the quasi-independent sub-markets. Firms in each industry i=1, ..., N are assumed to be risk-neutral and to produce a good that is characterized by a degree of product heterogeneity. The inclusion of product heterogeneity is necessary for the discussion of endogenous sunk costs. If firms were to produce completely homogenous goods, endogenous sunk costs on R&D would not help to differentiate products from each other.[11]

Market dualization implies that small and large firms produce, respectively, customized and standardized goods. The present model assumes that large firms produce standardized goods with customized capital, where the use of customized capital raises productive efficiency. Labor is non-specialized and only needed for the operation of customized capital. Small firms employ

[10] The model can be extended to the case of credit market imperfections, where firms differ in their access to external funds. See Bond and Van Reenen (2003, chapter 2) for details.

[11] See Sutton (1991, 1998) and Boone and Van Witteloostuijn (1999) for details.

standardized capital in the production of specialized goods. The customization of products is achieved through craftsmanship which requires the use of specialized labor. Given these specifications, the two market segments are assumed to draw labor from two independent pools: the market center uses non-specialized (unskilled) labor and the market periphery employs specialized (skilled) labor.[12]

Despite these differences, small and large firms operate the same production function. In each period, the output level of firm j in industry i (Y_{ji}) depends on firm-specific Hicks-neutral technology (A_{ji}), labor (N_{ji}), physical capital (K_{ji}), and human capital (H_{ji}) according to the following Cobb-Douglas production function:

$$Y_{ji,t} = A_{ji,t} K_{ji,t}^{1-\alpha} \left(N_{ji,t} H_{ji,t} \right)^{\alpha}. \tag{1}$$

The production function displays constant returns to scale in capital and labor, but increasing returns to scale when taking into account labor-augmenting (Harrod-neutral) human capital. Furthermore, the production function is characterized by the unit elasticity of substitution of the input factors.

The technology parameter of firm j in industry i (A_{ji}) follows a random walk with drift specified as

$$A_{ji,t} = \alpha_{Ai} + A_{ji,t-1} + \beta_{Aji} \left(\Delta RD_{ji,t} \right) + \epsilon_{Aji,t}. \tag{2}$$

The parameter α_{Ai} is a time-invariant industry-specific positive drift that reflects the importance of technical progress in production at the industry level. $\Delta RD_{ji,t}$ reflects the periodic improvement in technology resulting from firm-specific R&D. The variable is included to account for cross-firm differences in R&D-related productive efficiency and, accordingly, for cross-firm differences in output and size. ϵ_{Aji} is an i.i.d. random variable with zero mean and constant variance, i.e., $N \sim (0, \sigma^2)$.

Human capital is included to control for differences in the level of skills of specialized and non-specialized labor and, hence, for differences in the nominal wage paid in the market center and market periphery. Human capital evolves as a deterministic process defined as

[12] Alternatively, the market center and market periphery can also be said to employ low- and high-skilled labor. The same conclusions apply.

$$\mathsf{H}_{ji,t} = \alpha_{Hi} + \mathsf{H}_{ji,t-1} + \beta_{Hji}\mathsf{S}_{ji,t}.^{13} \tag{3}$$

Again, the parameter α_{Hi} is a time-invariant industry-specific positive drift, reflecting the effects of, for example, learning by doing. The variable $S_{ji,t}$ is a binary positive dummy that controls for the positive differential between the level of human capital in the market periphery and market center. The dummy equals one if the firm operates in the market periphery and, hence, employs specialized labor and zero otherwise.

Labor and capital are assumed to become immediately productive in period t.[14] Throughout the model, labor adjustment is assumed to be instantaneous and costless.[15] The capital stock $K_{ji,t}$ of firm j in industry i at time t, however, changes according to

$$K_{ji,t} = (1-\delta)\, K_{ji,t-1} + I_{ji,t}. \tag{4}$$

The parameter δ denotes the rate of capital depreciation which is assumed to be constant across firms and industries, with $0 < \delta < 1$. The variable I_t describes gross capital investment per unit of time and, hence, the capacity choice of firm j. Dependent on its focus, the firm may direct investment towards the accumulation of physical capital that functions on the basis of old established or new innovative technologies.[16] Investment is assumed to add to the capital stock immediately rather than with a one period delay.

Summarizing, firm-specific production crucially depends on technology and the stock of human and physical capital. Motivated by the importance of physical capital as determinant of firm output, the capital stock in period t is used as a proxy variable of firm size. We assume that small firms employ less capital than large firms.[17] As will be shown below, the size-related differences in the stock of capital are associated with size-related dissimilarities in investment behavior which feed back into the interest rate sensitivity of small and large firms.

[13] Human capital is modeled as a deterministic process to allow for a clear relationship between technology and prices. However, this assumption does not affect the conclusions of the model.

[14] One can argue that capital only becomes productive at a lag. Since the introduction of a lag confounds the readability of the model, none is included. This does not affect the conclusions.

[15] See Hall (2004) for evidence of low labor adjustment costs.

[16] Section 3.2 provides details on the investment options of firms.

[17] Kumar, Rajan, and Zingales (1999) show that physical capital-intensive industries are characterized by larger firms. Section 3.3 presents arguments according to which large firms do not only employ more capital but also more labor.

3.2 Investment Cost Function

According to equation (4), changes in the stock of capital require costly investment. A cost function $C(I_t, K_t)$ captures the effect of investment costs on capital accumulation. In line with, for example, Abel and Eberly (1994, 1996, 1997), Dixit and Pindyck (1994), and Letterie and Pfann (2003), the cost function of small and large firms consists of three components: a convex capital adjustment cost function $\left(\gamma I_t^m K_t^{-1}\right)$, a capital purchase/sale cost function $(p_{It} I_t)$, and a cost function related to the existing stock of capital $(p_{Kt} K_t)$. Following convention (e.g., Abel and Eberly, 1994; Caballero and Leahy, 1996; Bond and Van Reenen, 2003), the function $p_{Kt} K_t$ will be referred to as fixed cost function. As will be shown, the fixed cost function helps to explain the partial irreversibility of investment and accounts for infrequent and lumpy capital adjustment.

Interpreting the variables of the investment cost function, γ is a price parameter which is assumed to be size-independent and constant for positive and negative investment. The variable p_{It} denotes the price of one unit of capital investment I_t and p_{Kt} describes the fixed cost per unit of installed capital K_t at time t. We assume throughout this paper that the unit price of investment p_I, the fixed cost per unit of installed capital p_K, and γ exceed zero. The parameter m determines the functional form of the investment cost function, which is specified to be non-negative for all parameters m and, hence, for positive and negative investment values.[18]

Combining the cost components and suppressing subscripts j and i for firm and industry for ease of notation, the investment cost function of firm j is defined as

$$C(I_t, K_t) = p_{It} I_t + \nu \left(p_{Kt} K_t\right) + \gamma \frac{I_t^m}{K_t}. \tag{5}$$

ν depicts a dummy variable that equals one for non-zero investment and zero otherwise. The dummy variable is included to ensure that fixed costs of investment only arise for non-zero investment. The fixed costs of investment can be viewed as exogenous sunk costs which small- as well as large-sized firms incur in the process of capital accumulation. For example, small and large firms incur managerial and administrative costs when they decide on the acquisition of new capital. Once a new machine is purchased, its installation may require existing machines to be temporarily turned off, which results in costs of lost production. These costs are exogenous to each firm.

[18] In more detail, m is defined as m=2k with $k \in \mathbb{Z}$. Also see Bond and Van Reenen (2003) for additional explanations regarding the properties of a convex capital adjustment function.

Reflecting managerial and administrative costs and expenses related to lost production, the fixed cost per unit of existing capital p_K are identical for positive and negative investment. The fixed cost parameter p_K is assumed to increase with the existing stock of capital K and, therefore, with the size of firms. That is, p_K is a positive function of K. This relationship rests on organizational and informational inefficiencies at the level of the firm. These arise from complex hierarchical and governance structures and are more severe for large than for small firms. The inefficiencies result in conflicts of interests and moral hazard, which impede the coordination of tasks and the exchange of information.[19]

Considering the purchase/sale cost per unit of capital p_I, this price variable consists of an industry-specific component ϵ_i and a firm-specific component ϵ_j according to $p_{It} = \epsilon_{it} + \upsilon\epsilon_{jt}$. The structure of the capital purchase/sale cost function reflects two options that firms are left with to achieve a chosen capacity. The first option involves the use of standardized capital in the production process, which is available at the industry-specific price ϵ_i.[20] The second option specifies the use of customized capital, which requires the firm-specific price ϵ_j. ϵ_j is an endogenous sunk cost on technical progress that represents the price of R&D and the cost of capital customization.[21] This variable is included to approximate the endogenous sunk cost argument by Sutton (1991, 1998) and the underlying objective of large-sized firms to realize economies of scope and scale.[22] υ is a zero-one dummy variable that captures these two choices. The variable equals unity if a firm pays the firm-specific price ϵ_j and zero otherwise. In including only a dummy on investment in customized capital, firms that invest in customized capital at cost ϵ_j are also required to invest in industry-specific capital at price ϵ_i. Customized capital therefore supplements rather than replaces standardized capital.

In order to introduce partial irreversibility of investment, positive investment $I > 0$ and negative investment $I < 0$ take place at the purchase price p_I^+ and sale price p_I^- per unit of capital,

[19]See Ramírez and Espitia (2002) for a survey of the literature that discusses these issues.

[20]Alternatively stated, the industry-specific component reflects the cost of operating capital of average technological quality.

[21]The model does not control for the possibility that firm-specific technological innovations are used at the industry level. The reason is that the adoption of a firm-specific innovation at the industry level requires adjustment that needs to be captured by another cost variable. The inclusion of another cost measure confounds the readability of the model without providing additional details.

[22]The realization of scope economies gives rise to market dualization through a first-order inter-segment effect. A second-order intra-segment effect of market dualization results from large firms incurring endogenous sunk costs to gain a competitive lead in the market center via scale economies (cf. Boone and Van Witteloostuijn, 1999). The present model neglects this second-order scale effect and assumes that endogenous sunk costs affect output only through technology rather than scale economies.

respectively. Given the prevalence of asymmetric information problems in the market for used physical capital, the sale cost per unit of capital is contemplated to be lower than the corresponding purchase cost. That is, $p_I^+ > p_I^- > 0$. The difference between the purchase and sale price measures the extent to which expenses are sunk. Considering the components of the capital purchase price, the model assumes that the purchase price of firm-specific capital equals the purchase price of industry-specific capital, with $\epsilon_j^+ = \epsilon_i^+ > 0$.[23] As regards the sale price of firm-specific capital, it satisfies $\epsilon_j^- = 0$ because the costs of R&D and capital customization are sunk. This implies that the endogenous sunk cost on technical progress is only defined for positive investment levels. Industry-specific capital can be sold at price $\epsilon_i^- > 0$, where $\epsilon_i^+ > \epsilon_i^- > 0$ due to asymmetric information problems in the market for used capital.

As stated, the capital cost variable p_I reflects the price that accompanies the acquisition and disposal of one unit of either standardized or customized capital. Because $\epsilon_i^+ = \epsilon_j^+$ and $\epsilon_i^- > \epsilon_j^-$, the expenses associated with the purchase and sale of firm-specific customized capital are higher than those that result from positive and negative investment in industry-specific standardized capital. The present analysis assumes that the willingness of firms to incur the cost ϵ_j per unit of customized capital depends positively on the underlying capital stock and, consequently, on firm size. This relationship reflects the dependence of large-firm production on customized capital and suggests a positive link between the stock of capital used in production and the need for customized physical capital.[24] Summarizing these relationships, large firms base their investment decisions on ϵ_i and ϵ_j, whereas small firms only view ϵ_i as the relevant investment decision parameter. Cross-firm differences in technologies are, hence, attributable to cross-firm dissimilarities in the decision to invest in either industry- or firm-specific technologies.

Except for zero investment $I = 0$, the augmented investment cost function (5) is continuous and twice differentiable with respect to investment at all investment levels, with $\frac{\partial C(I_t, K_t)}{\partial I_t} > 0$. The discontinuity at $I = 0$ results from the discrepancy between the sale and purchase cost per unit of capital, i.e., $p_I^+ \neq p_I^-$. Attributable to the difference in the purchase and sale price of capital, it also holds that $\frac{\partial C\left(I_t^+, K_t\right)}{\partial I_t^+} > \frac{\partial C\left(I_t^-, K_t\right)}{\partial I_t^-}$, where I_t^+ and I_t^- depict positive and negative investment, respectively.

[23] Note, the conclusions of the model are not sensitive to the more restrictive assumption that differences in the degree of capital customization and sophistication cause the purchase price of firm-specific capital to exceed that of industry-specific capital.

[24] This claim does not interfere with the assumption that large and small firms produce generalized and standardized goods, respectively (cf. section 3.1).

3.3 Short-Run Profit Optimization

The production and augmented investment cost function in section 3.1 and 3.2, respectively, determine small- and large-firm investment behavior. As will be illustrated in section 3.4 and 3.5, investment is optimal when it maximizes the fundamental value of a firm. The underlying intertemporal maximization problem takes into account the level of instantaneous operating profits and the evolution of technology, human capital, and output prices. So far, we only discussed the periodic development of technology and human capital as stochastic and deterministic process, respectively (see section 3.1). This section presents the short-run profit function of firms and the process that describes the evolution of the output price. The underlying discussion highlights the short-run profit optimization problem of firms.

The short-run profit maximization problem of the firm is defined as

$$\pi\left(P_t, A_t, K_t, N_t, H_t\right) = \max\left[P_t f\left(A_t, K_t, N_t, H_t\right) - C\left(N_t\right)\right], \tag{6}$$

where P_t is the output price, $f(\cdot)$ denotes the production function, and $C(N_t)$ describes the costs of production. The function $C(N_t)$ equals $C(N_t) = w_t N_t$ and summarizes the costs of employing N units of labor at wage w at time t. In the short run, the physical and human capital stock is quasi-fixed and firms maximize profits by varying the input factor labor. Labor adjustment is assumed to be costless, i.e., costs related to retraining do not arise. An additional unit of labor is therefore instantaneously available at cost w_t.

The model features cross-segment differences in the price of labor. Because small firms produce customized goods with specialized labor, while large firms produce generalized goods with non-specialized labor, small firms are assumed to pay higher wages than large firms. The higher wage in the market periphery is needed to compensate workers for the costs associated with acquiring the necessary skill.[25] Given that small-firm production depends on the availability of specialized labor, small firms may also pay higher wages to discourage workers from turning over to competitors in the same market segment or from moving to the market center.

Although the conclusions of the model do not depend on this assumption, the cross-segment differences in wages are assumed to result in cross-segment differences in the output price. Given the use of skilled labor and the consequent higher wage, the output price of firms in the market periphery is likely to exceed that of firms in the market center. Besides cross-segment differences in the price of labor, the differential between prices in the market periphery and

[25] This, in turn, implies that the value of product customization accrues to the worker and not as mark up to the firm.

market center is also attributable to cross-segment differences in technology. Again, small firms are assumed to impose larger prices compared with large firms. This relationship reflects the R&D-related technology advantage of firms in the market center and the negative effect of technological advances on the costs of production through higher factor productivity.[26]

Because technology is assumed to evolve as a stochastic process, the interdependence of output price and technology causes prices to follow a stochastic process as well. In particular, we assume that the price level of firm j in industry i evolves as an AR(1) process with positive drift according to

$$\mathsf{P}_{ji,t} = \alpha_{\mathsf{P}i} + \mathsf{P}_{ji,t-1} + \epsilon_{\mathsf{P}ji,t}, \tag{7}$$

where $\epsilon_{\mathsf{P}ji}$ is an i.i.d. random variable. The error term is included to control for unexpected price disturbances, resulting from technology shocks or from supply shocks. Equation (7) can be criticized in that it describes the development of a firm's output price on the basis of ad hoc arguments rather than explicit pricing rules. Two reasons justify this approach. Firstly, the derivation of explicit pricing rules for firms in the market center and market periphery is beyond scope of the present study since it requires additional (ad hoc) assumptions about the curvature of the demand and cost functions in each market segment. Secondly, complex pricing structures are not derived since neither the periodic development of prices nor the predictions of the investment model depend on the underlying pricing rule.

Having specified the process that describes a firm's output price, technology, and human capital and given the investment cost and short-run profit function, we have introduced all variables which define the intertemporal investment problem of firms. The next two sections discuss the intertemporal investment problem and, accordingly, optimal investment behavior. We will show that optimal investment behavior maximizes the fundamental value of a firm. To facilitate the readability, subscript j and i for firm and industry are subsequently suppressed.

3.4 Fundamental Firm Value

In the long run, firm j is free to adjust the stock of productive capital. Since capital adjustment is costly, the firm decides on the optimal degree of investment activity by maximizing the

[26]See, for example, Rochelle, Laubach, and Williams (2003) for empirical evidence of the negative effect of technology on prices. Note, firms in the market center may also charge lower prices in response to technological advances in order to sustain intra-segment competition. This relationship describes the second-order intra-segment effect of market dualization through scale economies.

expected present value of net operating profits in each period. Net operating profits are defined as the difference between instantaneous operating profits and the costs of capital investment. In each period, the firm faces an intertemporal investment problem that arises from the periodic depreciation of capital and the costly adjustment thereof. In order to solve the optimization problem, the firm maximizes the expected present value of net profits with respect to investment according to

$$V(P_t, A_t, K_t, N_t, H_t) = \max_{I_{t+s}} E_t \left\{ \sum_{s=0}^{\infty} \beta_{t+s} \left[\pi \left(P_{t+s}, A_{t+s}, K_{t+s}, N_{t+s}, H_{t+s} \right) - C \left(I_{t+s}, K_{t+s} \right) \right] \right\}. \tag{8}$$

Here, β is the firm's discount factor defined as $\frac{1}{1+r_t}$, where r_t is the money market interest rate $r_{M,t}$ at time t adjusted for firm-specific risk $r_{FP,t}$. That is, r_t is defined as $r_t = r_{M,t} + r_{FP,t}$.[27] E_t is an expectations operator conditional on information available at time t. Equation (8) illustrates that the fundamental value of a firm is the present value of current and future net operating profits. Following the Bellman principle of optimality, the fundamental value of a firm equals the expected capital gain from future investment decisions and the level of net operating profits at time t (equation 9).

$$V(P_t, A_t, K_t, N_t, H_t) = \max_{I_t} \{ \pi (P_t, A_t, K_t, N_t, H_t) - C(I_t, K_t) + \beta_{t+1} E_t [V_{t+1}] \}. \tag{9}$$

Net operating profits are influenced by two sources of uncertainty, i.e., by the stochastic behavior of output prices and firm-specific technology.

The optimization problem in equation (9) is constrained by the process of capital accumulation (4) and by the evolution of technology (2) and output price (7). For these constraints, the intertemporal maximization problem at time t is put in terms of the Lagrangian expression

$$\begin{aligned} L_t = {} & \pi (P_t, A_t, K_t, N_t, H_t) - C(I_t, K_t) + \beta_{t+1} E_t [V_{t+1}] + \lambda_t [(1-\delta) K_{t-1} - K_t + I_t] + \\ & V_{Pt} (\alpha_P + P_{t-1} - P_t + \epsilon_{Pt}) + V_{At} (\alpha_A + A_{t-1} - A_t + \beta_A (\Delta RD_t) + \epsilon_{At}) + \\ & V_{Ht} (\alpha_H + H_{t-1} - H_t + \beta_H S_t). \end{aligned} \tag{10}$$

[27]The discount factor may also include an industry-specific premium. Because the analysis is only interested in the investment patterns of firms in the market center and market periphery of a particular industry, the discussion ignores industry-specific effects. This does not affect the conclusions of the model.

V_A, V_P, and V_H represent the shadow value of technology, output price, and human capital, respectively, and ϵ_A and ϵ_P denote random shocks to technology and output price, respectively.

Because the shadow value of capital λ_t is a crucial determinant of optimal investment behavior, the remainder of this section summarizes the variable's properties in more detail. A theoretical expression for the shadow value of capital at time t is obtained by differentiating equation (10) with respect to capital

$$\frac{\partial L_t}{\partial K_t} = \frac{\partial \pi_t}{\partial K_t} - \frac{\partial C_t}{\partial K_t} + \beta_{t+1}\frac{\partial E_t\left\{V_{t+1}\right\}}{\partial K_t} - \lambda_t = 0, \tag{11}$$

where $\frac{\partial \pi_t}{\partial K_t} = \frac{1}{\theta}\left(P_t A_t\right)^{\theta}\left(\frac{\alpha H_t}{w_t}\right)^{\theta-1}$ and $\frac{\partial C_t}{\partial K_t} = \left(\nu p_{Kt} - \gamma \frac{I_t^m}{K_t^2}\right)$. $\frac{\partial E_t\{V_{t+1}\}}{\partial K_t}$ is the contribution of one additional unit of physical capital today to the expected fundamental firm value at time t+1. This component can be written as the expected shadow value of inheriting one additional unit of capital from period t in period t+1: $\frac{\partial E_t\{V_{t+1}\}}{\partial K_t} = (1-\delta)\, E_t\left\{\lambda_{t+1}\right\}$.[28] Summarizing terms, equation (11) can be expressed as

$$\lambda_t = \frac{\partial \pi_t}{\partial K_t} - \frac{\partial C_t}{\partial K_t} + (1-\delta)\,\beta_{t+1} E_t\left\{\lambda_{t+1}\right\}. \tag{12}$$

This equation indicates that the shadow value of capital λ_t at time t combines the marginal operating profit of capital at time t, the marginal contribution of capital to capital installation costs at time t, and the expected shadow value of capital at time t+1. The expectations operator is solved by forward iteration. The corresponding result indicates that the shadow value of installed capital at time t equals the discounted expected present value of the future stream of marginal operating profits net the future marginal capital adjustment costs according to

$$\lambda_t = E_t\left\{\sum_{s=0}^{\infty}(1-\delta)^s \beta_{t+s}\left(\frac{\partial \pi_{t+s}}{\partial K_{t+s}} - \frac{\partial C_{t+s}}{\partial K_{t+s}}\right)\right\}. \tag{13}$$

Because $\frac{\partial \pi_t}{\partial K_t} > 0$ and $\frac{\partial C_t}{\partial K_t} < 0$, the shadow value of one unit of installed capital is positive.[29]

[28] See Bond and Van Reenen (2003, chapter 3) for additional details.

[29] Note, the first-order condition of the investment cost function might also be positive. Since γ is assumed to be the same for small and large firms, while p_K increases with firm size, this might be particularly true for large firms. To exclude this possibility, the present analysis assumes that technology raises the marginal operating profit of capital above the marginal contribution of capital to lower installation costs such that the shadow value of capital is still positive for large firms.

The property of the first-order condition of the instantaneous profit function results from the evolution of output price and technology as random walk with positive drift.

3.5 Intertemporal Value-Maximization

This section identifies the value maximizing investment level of small and large firms. Because $\lambda_t I_t$ and $C(I_t, K_t)$ are the only components in equation (10) that contain investment, we follow Abel and Eberly (1994) and summarize the intertemporal maximization problem in equation (10) as

$$\Phi(\lambda_t, K_t) = \max_{I_t} \{\lambda_t I_t - C(I_t, K_t)\}, \tag{14}$$

where Φ_t describes the net value of investment at time t. The solution to this optimization problem is subject to two distortions which give rise to lumpy and infrequent capital adjustment. The first distortion arises from the purchase and sale cost per unit of capital p_I and is subsequently referred to as unconstrained case. It is unconstrained because it defines optimal investment behavior to depend on the shadow value of capital and on the price of capital, while it disregards the investment effect of the fixed capital adjustment cost p_K. The second distortion results from the fixed adjustment cost per unit of installed capital p_K. We will illustrate that this cost component constrains investment behavior beyond the effect of the purchase/sale price of capital p_I. We introduce the corresponding investment behavior as constrained case. In order to facilitate the readability of the derivations, the profit, value, investment, net value, and augmented investment cost function are subsequently reported without arguments. That is, they are abbreviated as π_t, V_t, I_t, Φ_t, and C_t.

In order to derive an expression of the value maximizing unconstrained investment level, equation (14) is solved for the first-order condition with respect to investment. The first-order condition

$$\frac{\partial \Phi_t}{\partial I_t} = \lambda_t - \frac{\partial C_t}{\partial I_t} = \lambda_t - \left(p_{It} + \gamma m \frac{I_t^{m-1}}{K_t}\right) \tag{15}$$

shows that optimal investment is determined by the relationship between the marginal benefits (i.e., the contribution of one additional unit of capital to the fundamental firm value) and the marginal costs of investment. Solving equation (15) and using the information on the augmented investment cost function (5), optimal investment at time t is defined as

$$I_t^* = \left[\frac{(\lambda_t - p_{It})\, K_t}{\gamma m}\right]^{\frac{1}{m-1}}. \tag{16}$$

In line with Hayashi (1982), current and future expected output demand, output supply, and ultimately operating profits do not appear to have a direct impact on optimal investment, while it positively depends on the existing stock of capital. Equation (16) indicates that optimal investment is strictly increasing in the shadow value of installed capital λ. Furthermore, it shows that gross capital investment is only positive (negative) if the value of an additional unit of capital is larger (less) than the purchase (sale) price of capital. No investment arises if the shadow valuation of capital is in-between the sale and purchase price of capital. Summarizing these relationships between gross capital investment and the shadow value of capital, it holds that

$$\begin{aligned}
I^*(\lambda_t, K_t) < 0 \quad &\text{for} \quad \lambda_t < p_{It}^-, \\
I^*(\lambda_t, K_t) = 0 \quad &\text{for} \quad p_{It}^- \leq \lambda_t \leq p_{It}^+, \\
I^*(\lambda_t, K_t) > 0 \quad &\text{for} \quad \lambda_t > p_{It}^+.
\end{aligned} \tag{17}$$

The shadow value of one unit of installed capital λ is closely related to Tobin's marginal value of installed capital defined as $q_t = \frac{\lambda_t}{p_{It}}$. For ease of exposition, we predominantly present the optimization problem in terms of the shadow rather than marginal value of capital.[30]

Section 3.2 modeled the purchase price of capital as $p_{It}^+ = \epsilon_{it}^+ + \upsilon\epsilon_{jt}^+$. Given this specification of the price, the expression for positive investment in equation (17) shows that the decision process of firms involves two possible outcomes. Firms invest in standardized capital if $\epsilon_{it}^+ < \lambda_t \leq \epsilon_{it}^+ + \epsilon_{jt}^+$. By assumption, these firms are small. Investment in customized capital only arises if $\lambda_t > \epsilon_{it}^+ + \epsilon_{jt}^+$. Again by assumption, only large firms incur the endogenous sunk costs to purchase innovative capital which is needed for the realization of product differentiation advantages.

The relationships in equation (17) describe the value maximizing investment level for the unconstrained case, but do not represent the solution for constrained optimal investment. The difference originates from the nonnegative fixed costs of investment that have been ignored so far. Arising for non-zero investment, these costs affect the payoff function $\Phi(\lambda_t, K_t, I_t)$ and widen the range of inaction for which non-zero investment is costly. In order to be

[30] For details regarding the relationship between the shadow and marginal value of capital see Hayashi (1982) and Bond and Van Reenen (2003, chapter 3).

profitable, the shadow value of capital λ must be such that the underlying payoff function $\Phi(\lambda_t, K_t, I_t)$ assumes positive values for non-zero investment. In order to determine this value, the expression for optimal investment I_t^* from expression (16) is substituted into (14) according to

$$\Phi^*(\lambda_t, K_t) = (\lambda_t - p_{It}) \left[\frac{(\lambda_t - p_{It}) K_t}{\gamma m}\right]^{\frac{1}{m-1}} - \left(\nu (p_{Kt} K_t) + \gamma \frac{\left[\frac{(\lambda_t - p_{It}) K_t}{\gamma m}\right]^{\frac{1}{m-1}}}{K_t}\right). \tag{18}$$

Rewriting and summarizing terms yields

$$\Phi^*(\lambda_t, K_t) = \Omega (\lambda_t - p_{It})^{\frac{m}{m-1}} K_t^{\frac{1}{m-1}} - \nu (p_{Kt} K_t), \tag{19}$$

where $\Omega = \left(1 - \frac{1}{m}\right)(\gamma m)^{\frac{-1}{m-1}}$. In order to identify optimal investment behavior, expression (19) is solved for the threshold levels of λ for which optimal investment behavior asks for positive, negative, or zero investment. The thresholds are identified by imposing the condition $\Phi = 0$ for p_{It}^+ and p_{It}^-, alternatively. For this condition, positive and negative investment describe optimal investment behavior if

$$\lambda_t > \overline{\lambda}_t = p_{It}^+ + (\nu p_{Kt} \Psi_t)^{\frac{m-1}{m}},$$

$$\lambda_t < \underline{\lambda}_t = p_{It}^- - (\nu p_{Kt} \Psi_t)^{\frac{m-1}{m}}, \tag{20}$$

respectively, where $\Psi_t = \frac{K_t^{1-\frac{1}{m-1}}}{\Omega}$. Evidently, the relationship between the purchase/sale price per unit of capital p_I and the fixed price per unit of existing capital p_K is influenced by the interpretation of the price variables. The purchase price of capital p_I^+ is a cost to the firm, while the sale price p_I^- needs to be interpreted as a gain.

Using equation (20), the regime of zero investment reflects the optimal investment decision for values of λ in the interval $\underline{\lambda}_t \leq \lambda_t \leq \overline{\lambda}_t$, where $\overline{\lambda}$ and $\underline{\lambda}$ denote the upper and lower threshold of λ below and above which zero investment is undertaken. Given these relations, optimal investment behavior $\hat{I}(\lambda_t, K_t)$ can be summarized as

$$\hat{I}(\lambda_t, K_t) = \begin{cases} I^*(\lambda_t, K_t) < 0 & \text{if } \lambda_t < \underline{\lambda}_t \\ I^*(\lambda_t, K_t) = 0 & \text{if } \underline{\lambda}_t \leq \lambda_t \leq \overline{\lambda}_t \\ I^*(\lambda_t, K_t) > 0 & \text{if } \lambda_t > \overline{\lambda}_t. \end{cases} \tag{21}$$

The region of inactivity is positively related to the cost components of the augmented investment cost function $C(I_t, K_t)$, i.e., p_{It}, p_{Kt}, and γ. The higher these costs are, the larger the region of inactivity where investment is zero between the lower and upper threshold value of λ.[31]

Considering the threshold level of λ at which positive investment guarantees a positive payoff, the assumed positive relationship between the stock of capital and the purchase price per unit of capital p_I^+ suggests a threshold value that is higher for large than for small firms. Following the same argumentation as before, small firms invest in standardized capital if $\lambda_t > \overline{\lambda}_t$ for $p_{It}^+ = \epsilon_{it}^+$, while large firms invest in new innovate capital if $\lambda_t > \overline{\lambda}_t$ for $p_{It}^+ = \epsilon_{it}^+ + \epsilon_{jt}^+$. The size-related difference in the use of firm- and industry-specific capital becomes irrelevant in the case of negative investment. With the costs on firm-specific capital being sunk, large and small firms obtain the same per unit price for the sale of capital, i.e., ϵ_i^-. On the basis of this price measure, large and small firms disinvest at the same threshold level of λ.

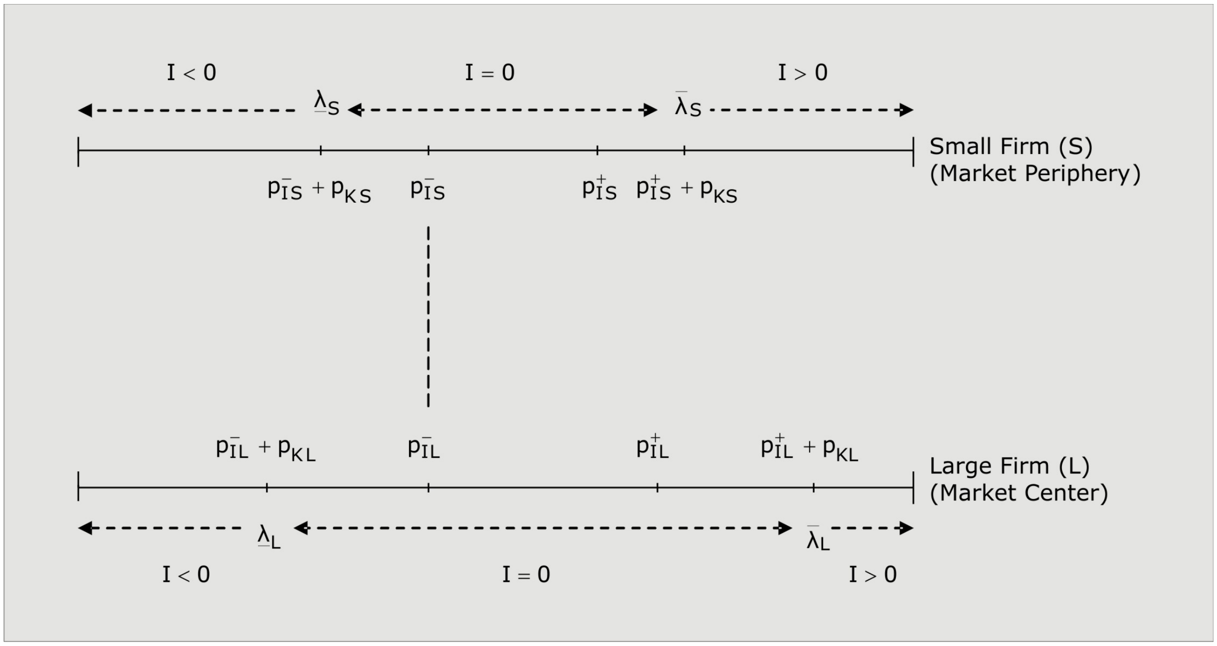
Size-related differences in the thresholds of negative investment arise from the fixed price per unit of existing capital p_K. For disinvestment, the variable p_K has to be interpreted as a price that firms pay rather than receive. Because large firms pay a higher fixed cost per unit of installed capital than small firms, the threshold level of disinvestment is negatively related to the size of firms. Along the same line, the positive relationship between the fixed cost per unit of installed capital p_K and the size of firms causes the threshold level of positive investment to be higher for large than for small firms.[32]

Given the properties of the price variables p_I and p_K, the range of zero investment is a positive function of firm size. Figure 1 summarizes the relationships for the case when the purchase price per unit of capital p_I^+ differs between small and large firms, while the sale price per unit of capital p_I^- is the same.

[31] Given the assumption that λ is nonnegative, $\underline{\lambda}$ is also nonnegative. If these conditions are met, negative investment can constitute an optimal investment decision.

[32] Recall, the fixed cost per unit of installed capital is assumed to be larger for large than for small firms. This relationship rests on organizational and informational inefficiencies at the firm level which are assumed to be more pronounced for large firms.

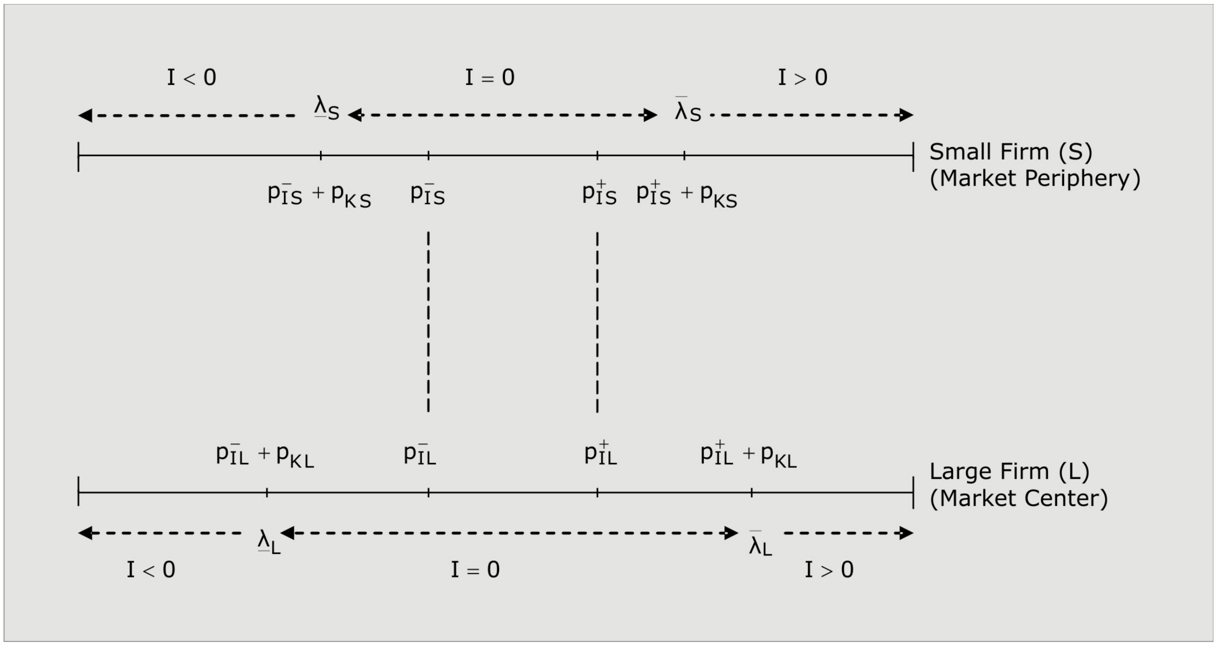
Figure 1: Optimal Small- and Large-Firm Investment Behavior with Size-Dependent Capital



$\underline{\lambda}_S$ and $\underline{\lambda}_L$ denote the lower investment threshold levels for small and large firms, respectively and $\overline{\lambda}_S$ and $\overline{\lambda}_L$ represent the corresponding upper threshold levels. The variables p_I^- and p_I^+ describe the sale and purchase price per unit of capital, respectively. The variable p_K denotes the fixed cost of capital adjustment per unit of existing capital.

The relationships so far attribute differences in the threshold levels of zero and non-zero investment between small and large firms to size-related asymmetries (i) in the type and, hence, per unit price of capital (p_I and (ii) in the degree of organizational and informational inefficiencies and, hence, in the fixed price per unit of capital adjustment p_K. While the type of capital affects the cost per unit of investment p_I, inefficiencies determine the fixed cost per unit of capital adjustment p_K. One may argue, however, that the assumed dependence of small- and large-firm production on different types of capital is overly restrictive and that the cost per unit of capital investment p_I does not differ between small and large firms. Alternatively, one may question the dual market assumption. Disregarding this assumption and assuming that small and large firms employ similar types of capital, we still find the range of investment inactivity to increase with firm size. The size-related asymmetries in the threshold levels of zero and non-zero investment are due to differences in the fixed capital adjustment cost per unit of installed capital p_K. This price variable is, thus, the stronger source of asymmetry in the investment behavior of small and large firms. Differences in the type of capital only amplify asymmetries in the optimal investment behavior of small and large firms. Figure 2 illustrates the corresponding relationships.

Figure 2: Optimal Small- and Large-Firm Investment Behavior with Size-Independent Capital



See the notes to Figure 1. Figure 2 has the same dimension as Figure 1. The sale and purchase price per unit of capital p_I^- and p_I^+ is the same for small and large firms, which reflects the size independence of the type of capital. Size-related differences only prevail with respect to the fixed cost of capital adjustment p_K per unit of existing capital.

Summarizing the results, the discussion shows that the solution to the intertemporal investment problem depends on two factors. The first factor is the actual firm-specific shadow value of installed capital λ. The second factor refers to the components of the augmented investment cost function which determine the threshold levels of λ above and below which positive and negative investment is undertaken. Because these boundaries do not coincide, they also define the region in which firms do not invest. Differences in the investment decisions of small and large firms in a dual market structure arise from size-related dissimilarities in the fixed (exogenous) adjustment cost per unit of installed capital and in the endogenous sunk cost per unit of capital. We find the fixed cost per unit of capital adjustment to be the more important source of asymmetries in the investment behavior of small and large firms.

The present model also allows for inferences regarding the degree of gradualism at which small and large firms adjust investment. In line with Cabral (1995), we predict small firms to invest more gradually in comparison to large firms given a smaller range of inaction. However, the size-related differences in investment behavior do not result from size-related asymmetries in the probability of industry exit as in Cabral (1995), but from dissimilarities in the capital purchase/sale cost per unit of capital p_I. In addition, we propose that discrete jumps in investment due to the fixed capital adjustment cost per unit of installed capital p_K are less accentuated for small than for large firms. The following section uses the results of the theoretical model to answer the question whether size-related differences in the relative importance of fixed capital adjustment costs and endogenous sunk costs explain differences in the sensitivity of small- and large-firm investment to changes in monetary policy.

4 Firm Size and Interest Rate Sensitivity

Equation (10) in combination with equation (13) illustrates that fluctuations in the fundamental value of a firm do not only stem from changes in technology and capital. Instead, changes in the firm-specific interest rate r - defined as the money market interest rate r_M adjusted for firm-specific risk r_{FP} - also influence the fundamental firm value and, accordingly, optimal investment behavior. This section discusses the response of small- and large-firm investment to an increase in the money market interest rate, i.e., to a tightening in monetary policy. We will show that the interest rate response of small- and large-firm investment differs and that size-related differences are due to size-related dissimilarities (i) in the range of zero and non-zero investment activity and (ii) in the per unit fixed cost of capital adjustment p_K.

In reality, investment decisions do not depend on the money market (i.e., short-term) interest rate, but on long-term rates. We approximate monetary policy changes with the money market interest rate for illustrative purposes, noting that long-term rates are a function of short-term rates. Motivated by the expectations theory of the term structure (Hicks, 1939) and the observation of upward sloping yield curves, we assume that a money market interest rate shock changes the long-term interest rate in the same direction given that long-term rates reflect the average expected level of short-term interest rates over the relevant horizon.[33] Because of these relationships, we discuss the interest rate response of small- and large-firm investment in terms of the money market interest rate.

In order to focus the analysis, we impose the following simplifying assumptions. Firstly, small

[33] We ignore any perverse effects of expected inflation on the long-term interest rate and assume that term and risk premiums are time-invariant. Term and risk premiums are, hence, not allowed to offset the effect of changes in the short-term interest rate on long-term rates. Evans and Marshall (1998) and Diebold, Rudebusch, and Arouba (2003), among others, provide empirical evidence in favor of the expectations hypothesis. Ellingsen and Söderström (2001, 2003) develop a theoretical model and report evidence according to which endogenous (exogenous) monetary policy changes cause long-term interest rates to be positively (negatively) related to short-term interest rates. There, endogenous changes are related to the state of the economy, while exogenous changes are due to changes in the monetary policy preferences of central bankers.

and large firms do not differ in terms of firm-specific risk r_{FP} and with respect to the interest rate sensitivity of the firm-specific risk premium. These assumptions ensure that the theoretical results are attributable to size-related differences in investment expenditures per unit of capital and not to size-related asymmetries in the degree of riskiness which may result in credit constraints due to credit market imperfections. The main conclusions are robust to these assumptions. In fact, the results would even strengthen when we would follow the common literature and assume that small firms are riskier than large firms.[34]

Secondly, we contemplate that small and large firms operate in the region of investment inactivity prior to the interest rate shock. The position of all firms within the range of zero investment is determined by the shadow value of capital in equation (13) which is assumed to be the same for small and large firms, i.e., $\lambda_{small} \cong \lambda_{large}$ at the time of the change in the money market interest rate. This is a long-run equilibrium condition which holds when the degree of risk in the market center equals the degree of risk in the market periphery. For equal risk, persistent differentials in the shadow value of capital cannot prevail because they are eliminated in course of an arbitrage process between the market center and market periphery.[35]

Analytical conclusions are drawn by assuming that the interest rate response of the shadow value of capital of small and large firms is identical. In order to define the sensitivity of the shadow value of capital to a change in the money market interest rate, we start by explicitly defining the time discount factor β as the combination of the money market interest rate r_M and the firm-specific risk premium r_{FP} according to

$$\beta_t = \frac{1}{1 + r_{M,t} + r_{FP,t}} = \frac{1}{1 + r_t}. \tag{22}$$

The firm-specific risk premium is a function of the money market interest rate defined as $r_{FP,t} = \alpha r_{M,t}$, where $\alpha > 0$. The time discount factor at time t accordingly equals

[34] See Baas and Schrooten (2005) for a theoretical model which reports higher loan interest rates for small than for large firms even in relationship banking. Elsas and Krahnen (1998), Harhoff and Körting (1998), and Gambacorta (2005), among others, report empirical evidence of an inverse relationship between firm size and credit spreads in Germany and Italy.

[35] Note, the long-run equilibrium condition $\lambda^* \cong \lambda_{small} \cong \lambda_{large}$ holds even if small and large firms differ in terms of risk. The cross-firm heterogeneity in riskiness is reflected in the risk-adjusted discount factor β and, hence, in the fundamental firm value (cf. equation 8).

$$\beta_t = \frac{1}{1 + r_t} = \frac{1}{1 + (1 + \alpha)\, r_{M,t}}. \tag{23}$$

Because small and large firms are equally risky, we have $\alpha_{small} = \alpha_{large}$. For small and large firms, the response of the shadow value of capital at time t with respect to a change in the money market interest rate at time t+1 and at time t+s then equals

$$\frac{\partial \lambda_t}{\partial r_{M,t+1}} = -\frac{(1-\delta)(1+\alpha)\, r_{M,t+1}}{(1 + (1+\alpha)\, r_{M,t+1})^2} E(\lambda_{t+1}), \tag{24}$$

$$\frac{\partial \lambda_t}{\partial r_{M,t+s}} = E_t \left\{ \sum_{s=0}^{\infty} -\frac{(1-\delta)^s (1+\alpha)\, r_{M,t+s}}{(1 + (1+\alpha)\, r_{M,t+s})^2} \left(\frac{\partial \pi_{t+s}}{\partial K_{t+s}} - \frac{\partial C_{t+s}}{\partial K_{t+s}} \right) \right\}, \tag{25}$$

respectively.[36] As indicated, the interest rate response of small- and large-firm investment is the same when the shadow value of capital is at the size-independent long-run equilibrium value λ^* at the time of the interest rate change. Furthermore, we assume that the rate of capital depreciation is independent of firm size and, hence, the same for customized and standardized capital and that persistent differentials in net operating profits are infeasible because of arbitrage.

Given these preliminaries, we illustrate the response of large and small-firm investment to a monetary policy contraction for two cases which differ in terms of the assumed magnitude of the interest rate shock. Case 1 discusses the investment effects of a small increase in the money market interest rate. For this scenario, large firms are assumed to move within their range of investment inactivity without crossing the threshold level of negative investment. Opposite to this, small firms are assumed to leave the range of zero investment, starting to disinvest. Case 2 represents the investment effects of a large increase in the money market interest rate. The contraction in monetary policy is such that small as well as large firms cross the threshold levels associated with negative investment. The discussion of case 1 and 2 will show that size-related differences in the interest rate response of investment are primarily due to size-related differences in the fixed cost per unit of installed capital p_K. The fixed cost affects the interest rate sensitivity of investment through its effect on the magnitude of the discrete jump in capital which prevails once the shadow value of capital λ crosses the threshold of zero and non-zero investment.

[36] Equation (25) is derived using equation (13).

Figure 3 illustrates the effect of a small (case 1) and large (case 2) interest rate shock on the investment behavior of small and large firms.[37] The picture is drawn by assuming that small and large firms, respectively, employ standardized and customized capital. As noted in section 3.5, the conclusions of the model are robust to this assumption. In line with the arguments above (cf. equation 24 and 25), the shadow value of large- and small-firm capital reacts to the same extent to a change in the money market interest rate.

Considering case 1 of a change in monetary policy, a small increase in the money market interest rate lowers the shadow value of capital of small and large firms from λ^* to λ_{SI}. The change in the shadow value of capital causes small firms to adjust their investment behavior: small firms move from the region of investment inactivity to the range of disinvestment. Small-firm investment falls by $\overline{0A}$ in due course, with the strength of the effect being determined by the fixed cost per unit of capital adjustment p_K. Different to small firms, the interest rate response of large-firm investment is confined to adjustments within the range of zero investment. Large firms move closer to the boundaries of negative investment but do not cross the threshold. The asymmetry in the interest rate sensitivity of small- and large-firm investment reflects the size-related difference in the range of investment inactivity which originates from size-related differences in the investment expenditures per unit of capital (p_I, p_K).

The size-related asymmetry in the interest rate sensitivity of small and large firms coheres well with the empirical finding by, for example, Gertler and Gilchrist (1994), Oliner and Rudebusch (1996), Ganley and Salmon (1997), De Bondt (2000), Dedola and Lippi (2005), and Ehrmann (2004) according to which small firms are relatively more responsive to interest rate shocks than large firms. However, it contradicts the evidence by Carlino and DeFina (1998, 1999a, 1999b, 2000), Mojon, Smets, and Vermeulen (2002), and Arnold and Vrugt (2004). The latter evidence can theoretically be explained with case 2 which stresses the response of investment to a large interest rate shock. Figure 3 illustrates a large interest rate shock as a decline in the shadow value of capital of small and large firms from λ^* to λ_{LI}. The decline in λ causes small as well as large firms to adjust their investment behavior: small and large firms move from the region of investment inactivity to the region of disinvestment. When crossing the threshold levels, small- and large-firm investment behavior displays discrete jumps. Investment by small and large firms falls by $\overline{0B}$ and $\overline{0C}$, respectively. Because the fixed cost per unit of installed capital p_K increases with the size of firms, the discrete jumps are more accentuated for large than for small firms, with $\overline{0C} > \overline{0B}$. Stated differently, large-firm investment is more interest rate sensitive than small-firm investment for large interest rate changes.

[37] Note, Figure 3 reflects arbitrary values. The shape of the graph is chosen for illustrative purpose.

Figure 3: The Investment Effects of A Small and Large Interest Rate Shock

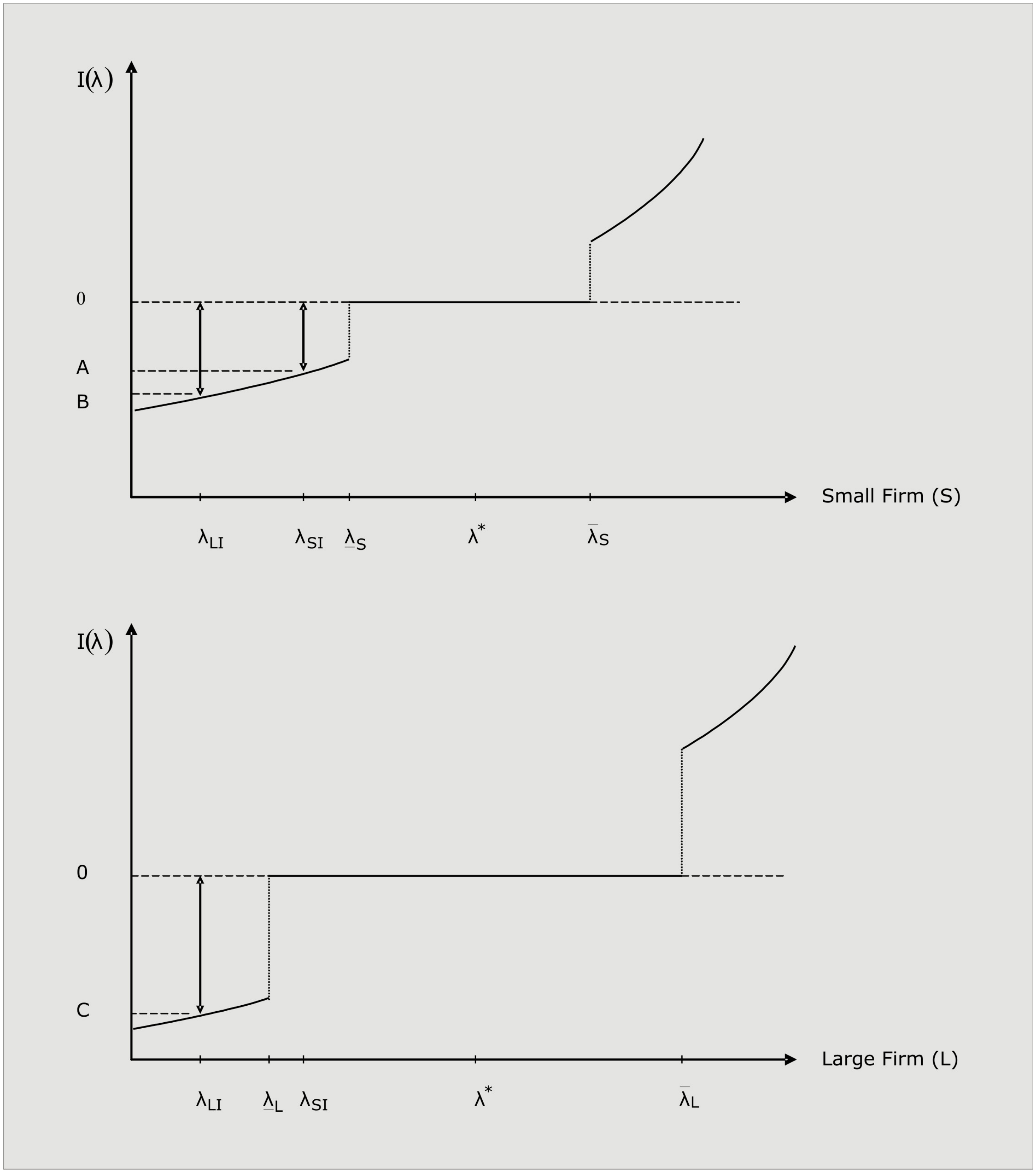


Figure 3 is adopted from Böhm and Funke (1999). The solid lines denote the investment path of firms. λ^* denotes the equilibrium shadow value of capital, which is the same for small and large firms. λ_{SI} and λ_{LI} represent the shadow value of capital prevailing after the 'small' and 'large' interest rate shock, respectively. Figure 3 is drawn for the case of linear homogeneity of investment and capital in the investment cost function. Furthermore, the interest rate sensitivity of the shadow value of capital is assumed to be the same for small and large firms. Note, the small firm panel has the same dimension as the large firm panel. For example, λ^*, λ_{SI}, and λ_{LI} are at the same position in both panels.

Summarizing the results, we stress the role of size-related asymmetries in investment irreversibility as source of differences in the interest rate response of small and large firms. We show that the interest rate sensitivity of small- and large-firm investment depends on the cost per unit of capital adjustment through its effect on the range of non-zero and zero investment activity. Furthermore, the interest rate response is determined by the magnitude of the monetary policy change that determines the extent to which small- as well as large-firm investment displays discrete jumps. We find that large firms do not move as often as small firms, but when they move, the change in investment is more pronounced than that of small firms. Overall, we illustrate that monetary policy shocks of different magnitudes have asymmetric effects on large- and small-firm investment. This, however, suggests that conclusions as to the existence of small firm size effects of monetary policy crucially depend on the magnitude of the monetary policy change.

5 Conclusion

This paper presented a dynamic investment model that aimed at explaining differences in the interest rate sensitivity of small- and large-sized firms. Different to existing studies on the firm size effects of monetary policy, the importance of firms as monetary transmission channel does not result from credit market imperfections, but in investment irreversibility. The theoretical model suggests that conclusions as to the interest rate sensitivity of small and large firms depend on two interacting factors: the adjustment cost per unit of capital and the magnitude of the monetary policy shock.

As to the first factor, the capital adjustment cost function was modeled to consist of endogenous and exogenous (fixed) investment expenditures. Endogenous sunk costs relate to R&D expenditures and affect the type of capital that firms operate, while exogenous sunk costs arise from organizational and informational inefficiencies. We have shown that the adjustment costs per unit of capital determine the width of the region for which zero and non-zero investment is optimal. Assuming a dual market structure, the adjustment costs per unit of capital and, hence, the region of investment inactivity are positively related to firm size. The size-related differences in the adjustment costs per unit of capital and, hence, in the range of investment inactivity suggest, on the one hand, that small firms change investment regimes more frequently than large firms. On the other hand, if small and large firms change investment regimes, size-related differences in the fixed cost per unit of existing capital cause swings in large-firm investment to be more accentuated than swings in small-firm investment. This finding is in line with the prediction by Cabral (1995) according to which small firms invest more gradually than large firms.

Considering the second factor, the magnitude of the interest rate change was shown to determine the investment response of small and large firms: small firms change investment regimes for smaller monetary policy shocks than large firms. For pronounced changes in monetary policy, the investment response of large firms was predicted to be stronger than that of small firms. Again, the size-related asymmetries arise from differences in the adjustment cost per unit of capital and from the consequent dissimilarities in the width of the range of investment inactivity.

We also argued that the size-related differences in investment behavior and in the interest rate sensitivity of firm investment prevail even if large firms do not incur endogenous sunk costs and small and large firms, consequently, operate similar types of capital. While the assumption of a dual market structure amplifies the main conclusions of the present model, they do not depend on it. Fixed capital adjustment costs per unit of existing capital have the strongest effect on the investment behavior of small and large firms and on the interest rate response of firm investment. Being at the core of size-related organizational and informational inefficiencies, fixed capital investment expenditures affect investment behavior regardless of the underlying market structure.

In summary, the interest rate sensitivity of small and large firms is determined by the cost of capital adjustment and by the magnitude of the change in the money market interest rate. Because the interest rate response of small and large firms depends on the relative importance of these factors, conclusions as to the nature of the relationship between the interest rate sensitivity of firm investment and firm size cannot clearly be drawn. This finding, in turn, indicates that the effectiveness of monetary policy cannot unambiguously be linked to the relative share of small firms in an economy as is frequently done in empirical work. Instead, we conclude that large firms may also drive monetary policy effectiveness via an investment channel and the underlying degree of investment irreversibility. This, in turn, suggests that tests for firm size effects of monetary policy should allow for small and large firm size effects.

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