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# Credit constraints, endogenous innovations, and price setting in international trade\*

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## Abstract

We introduce credit frictions motivated by moral hazard in a general equilibrium model of international trade with two dimensions of heterogeneity and endogenous investments. Firms' competitiveness consists of capabilities to conduct process and quality innovations at low costs, whereas investment outlays have to be financed by external capital. We show that the scope for vertical product differentiation in a sector determines how credit tightening affects investment and price setting. Consistent with recent empirical evidence, our model rationalizes positive as well as negative correlations of firm-level FOB prices with financial frictions and variable trade costs. Faced with an increase in the borrowing rate, producers reduce both types of innovation resulting in opposing effects on marginal production costs and prices. In general equilibrium, financial frictions intensify quality-based (cost-based) sorting of firms if the scope for vertical product differentiation is high (low). Consequently, credit tightening leads to firm exit, increased innovation activity among existing suppliers, and welfare losses that are larger in sectors with low investment intensity.

*JEL Classification:* F12, G32, L11

*Keywords:* international trade, external finance, credit constraints, moral hazard, quality, innovation, product prices.

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# 1 Introduction

A growing empirical literature documents negative effects of credit constraints on firms' export behavior. Exporting usually requires additional upfront costs for investments in marketing, capacity, product customization or distribution networks. Transportation leads to longer time lags between investment outlays and profit realization.<sup>1</sup> Consequently, empirical studies find that credit rationing decreases firm-level exports and reduces the probability of serving foreign markets (Berman and Héricourt, 2010; Minetti and Zhu, 2011; Muûls, 2014). Recent theoretical work based on fixed upfront costs and firm heterogeneity à la Melitz (2003) shows that financial frictions prevent foreign market entry of low productivity firms (e.g. Manova, 2013). Besides intensified productivity sorting, credit constraints and leverage negatively affect exporters' choice of product quality (Fan, Lai, and Li, 2015; Bernini, Guillou, and Bellone, 2013; Ciani and Bartoli, 2014). Firm-level studies document a positive relation of prices with firm size which points to competition through quality (Baldwin and Harrigan, 2011; Johnson, 2012; Kugler and Verhoogen, 2012; Crozet, Head, and Mayer, 2012). In contrast, cost-based productivity sorting à la Melitz (2003) suggests a negative correlation between prices and firm size (Roberts and Supina, 1996; Foster, Haltiwanger, and Syverson, 2008).

Depending on the importance of quality differentiation, recent empirical studies find opposing effects of credit frictions on price setting. For Italian firm-level data, Secchi, Tamagni, and Tomasi (2014) show that financially constrained exporters charge higher prices than unconstrained firms within the same product-destination market, whereas this positive relationship is reduced for product categories with high vertical differentiation. The authors follow Kugler and Verhoogen (2012) and measure the scope for vertical product differentiation as the ratio of advertising and R&D expenditures to total sales in U.S. industries. Using Chinese firm-level data, Fan et al. (2015) find negative effects of financial frictions on FOB prices. Furthermore, Fan, Li, and Yeaple (2014) show that tariff reductions induce quality upgrading associated with higher prices in highly differentiated sectors and lower prices in non-differentiated sectors.

Motivated by this empirical evidence, we analyze the effects of credit frictions on endogenous innovation choices, price setting and selection into exporting when both cost-based productivity and product quality determine the competitiveness of a producer. The main message of this paper is that credit tightening increases price (quality) competition if the sectoral scope for vertical product differentiation is low (high). Therefore, we develop a

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<sup>1</sup>See Amiti and Weinstein (2011), Chor and Manova (2012), as well as Feenstra, Li, and Yu (2014). Contessi and de Nicola (2012) as well as Manova and Foley (2014) provide reviews of the trade and finance literature.

general equilibrium model of international trade with credit constraints, two sources of firm heterogeneity and endogenous sunk costs. We allow for both cost-based and quality-based sorting as producers differ in capabilities to conduct process and quality innovations. Investments are associated with endogenous sunk costs that decrease in firm-specific capabilities. In contrast to standard models with monopolistic competition, innovation choices endogenously determine marginal production costs. Depending on their capabilities, firms choose different investment levels and prices. Process innovations decrease marginal costs and hence increase the cost-based productivity of a firm for any given quality level. Whereas this channel is closely related to productivity sorting in Melitz (2003), the second type of investment is motivated by the quality and trade literature. Quality innovations shift demand up at the expense of higher marginal production costs. The two types of innovation are complements as they increase price-adjusted quality and thus profits. Firms have to raise external capital for investment outlays, whereas labor is used for fixed and variable production costs. Based on Holmstrom and Tirole (1997), we motivate credit constraints by moral hazard between borrowing firms and outside investors. In equilibrium, only the most capable firms overcome financial frictions and become exporters, whereas some low capability producers with profitable investment projects fail to borrow external capital and exit the market.

We use this framework to show that the scope for vertical product differentiation in a sector determines how different financial shocks affect optimal firm behavior and export performance. Consistent with the empirical evidence mentioned above, our model rationalizes positive as well as negative relations of firm-level FOB prices with trade and credit costs. An increase in the borrowing rate negatively affects both types of innovation and triggers quality as well as cost effects that influence marginal production costs and thus optimal prices in opposite directions. Lower process innovations increase marginal costs (cost effect), whereas reduced product quality decreases prices (quality effect). If the scope for vertical product differentiation is high (low), the quality (cost) effect dominates and tighter credit conditions are associated with lower (higher) firm-level prices. This measure for quality differentiation is defined as the ratio of expenditures associated with product upgrades relative to investment outlays for processes. Theoretically, this ratio is independent of firm capabilities and only determined by exogenous technology parameters. Empirically, the measure is closely related to sectoral proxies of vertical differentiation used in firm-level studies.<sup>2</sup> Analogously, changes in variable trade costs induce opposing quality and cost effects as well.

We analyze the effects of credit frictions on investment and price setting both in partial and general equilibrium. Whereas the partial equilibrium results could be interpreted as short-term effects of credit tightening with a fixed number of suppliers, the general equi-

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<sup>2</sup>See Sutton (2001) and Kugler and Verhoogen (2012) as well as the discussion in section 4.

librium scenario allows for adjustments along the extensive margin. In general equilibrium, stronger credit frictions reduce the number of active producers and intensify quality-based (cost-based) sorting of firms if the scope for vertical product differentiation is high (low). In contrast to partial equilibrium, innovation activity as well as firm size of existing suppliers increases. Intuitively, the negative effect of credit frictions along the extensive margin enhances the benefits of investments for active firms resulting in an equilibrium with a lower number of producers that are larger on average. Furthermore, we show that credit tightening leads to welfare losses that differ across sectors with high and low investment intensity (either quality or cost-based). In sectors with low investment intensity, credit frictions induce stronger reactions along the extensive margin and thus lead to larger welfare losses. In contrast, an increase in the borrowing rate that is not caused by financial imperfections, but rather a decrease in capital supply, leads to negative reactions along the intensive margin. This cost shock causes stronger within-firm adjustments and thus larger welfare losses in sectors with high investment intensity.

Our paper differs from the theoretical trade and finance literature in several important aspects. First, we analyze the impact of credit frictions in a framework with both cost-based and quality-based sorting. The scope for vertical product differentiation in a sector determines the selection pattern of firms and how financial shocks affect optimal investment and pricing behavior. Second, we consider external financing of investment outlays instead of trade related upfront costs. Third, we allow for credit constraints not only among exporters, but also among non-exporters. Fourth, we do not restrict our analysis to partial equilibrium, but rather show that general equilibrium effects change firm responses to credit tightening. Finally, we investigate the welfare implications of financial shocks. The next section reviews related theoretical literature. Section 3 sets up the model and derives optimal firm behavior. In part 4, we analyze the effects of financial shocks and of trade liberalization on investment and price setting in partial equilibrium. The following two sections discuss credit frictions in general equilibrium. Finally, section 7 concludes.

## 2 Related theoretical literature

Most closely related to our theoretical setup with two dimensions of heterogeneity, Hallak and Sivadasan (2013) and Sutton (2007) develop two-attribute firm models of international trade with endogenous sunk costs. Besides Melitz-type productivity, Hallak and Sivadasan (2013) allow producers to differ in their ability to develop high-quality products at low fixed outlays. We additionally consider endogenous process investments and introduce credit frictions. Whereas our framework is based on monopolistic competition, Sutton (2007) considers

Cournot competition and non-CES preferences and thus allows only for vertical product differentiation but neglects horizontal differentiation. Similar to these papers, cost-based and quality-based capabilities jointly determine firms' competitiveness in our model and are summarized in a one-dimensional productivity measure related to Melitz (2003). Whereas we focus on single product manufacturers, Bernard, Redding, and Schott (2011) introduce heterogeneity in product attributes within the boundaries of multi-product firms that differ in productivity as in Melitz (2003). In a multi-product firm model with flexible manufacturing and quality investment, Eckel, Iacovone, Javorcik, and Neary (2015) show that prices fall with distance from the core product (quality-based competence) in differentiated-good sectors, but the opposite holds in non-differentiated sectors (cost-based competence).

Closely related to our analysis, Fan et al. (2014) extend a Melitz-type partial equilibrium model by endogenous quality choice to rationalize positive as well as negative relations of firm-level FOB prices with trade costs depending on the sectoral scope for vertical product differentiation. Fan et al. (2015) build on Arkolakis (2010) as well as Manova (2013) and differentiate between exogenous and endogenous quality. The authors show that financially constrained firms sell at higher prices when quality is exogenous, whereas the opposite holds in case of endogenous quality choice. In contrast, our model explains the prevalence of quality and cost effects when firms endogenously choose two innovation types that affect marginal production costs and thus prices in opposite ways. Furthermore, we analyze the effects of financial shocks in general equilibrium.

Additionally, this paper is related to work that considers investment decisions of heterogeneous firms. Bustos (2011), Lileeva and Trefler (2010) as well as Yeaple (2005) allow for process innovations that reduce marginal production costs. Consistent with our framework, these models predict that trade liberalization increases the incentives of technology upgrading. With respect to quality, we build on recent efforts to extend international trade models by quality sorting (Baldwin and Harrigan, 2011; Johnson, 2012) as well as endogenous quality and input choices (Kugler and Verhoogen, 2012; Antoniadis, 2015).

Furthermore, this paper is related to a growing literature on financial frictions and international trade with heterogeneous firms. These models are mainly based on productivity sorting à la Melitz (2003) and focus on financial constraints of exporters. In contrast, we assume that domestic as well as international sellers face credit frictions concerning endogenous innovation choices. Manova (2013) considers external financing of fixed and variable export costs and motivates credit constraints by imperfect financial contractibility. By introducing liquidity as a second source of heterogeneity, Chaney (2013) and Suwantaradon (2012) break up the one-to-one relationship between productivity and firm success in the presence of credit constraints. While we assume that endogenous innovations have to be

financed by external capital, these approaches stress the role of internal funds for financing of fixed export costs (Chaney, 2013) and capital inputs (Suwantaradon, 2012). Feenstra et al. (2014) introduce financial frictions by information asymmetry between firms and a monopolistic bank. Instead, we assume perfect competition in the financial sector and symmetric information with respect to firm characteristics, but ex-post moral hazard motivated by Holmstrom and Tirole (1997) introduces financial frictions.

Closely related to our notion of credit constraints, four other papers introduce imperfect capital markets motivated by Holmstrom and Tirole (1997) in international trade settings. First, von Ehrlich and Seidel (2013) analyze the impact of financial frictions on agglomeration of industries in a new economic geography model based on Krugman (1991). Second, Egger and Keuschnigg (2015) show how discrete R&D investment choices generate endogenous financial constraints. Third, Irlacher and Unger (2015) introduce firm-specific credit frictions and endogenous borrowing costs in a model of international trade. Fourth, in the framework of Antràs and Caballero (2009), firms engage in FDI as a response to imperfect financial contracting and weak investor protection in the host country. Related to that, Buch, Kesternich, Lipponer, and Schnitzer (2010) analyze the impact of financial frictions on FDI based on Helpman, Melitz, and Yeaple (2004). Other work considers credit frictions in the model of Melitz and Ottaviano (2008) with varying markups (Peters and Schnitzer, 2015; Mayneris, 2011).

### 3 Setup of the model

To analyze the impact of credit conditions on innovation and optimal price setting, this section presents a general equilibrium model of international trade with two sources of firm heterogeneity. We consider two symmetric countries with population of size  $L$  and capital endowment  $K$ , trading in differentiated varieties. Producers differ in their capabilities to introduce process and quality innovations at low costs. Motivated by a time lag between innovation activity and profit realization, we assume that investment outlays have to be financed by external capital, whereas labor is used for fixed and variable production costs. Capital costs are denoted by the gross interest rate  $r > 1$ , and the nominal wage is chosen as numéraire ( $w = 1$ ). Following Holmstrom and Tirole (1997), we introduce a non-verifiable project choice of firms which leads to moral hazard and credit frictions. The following subsections discuss the optimal behavior of consumers and producers.

### 3.1 Consumers

Preferences of a representative consumer in one country are characterized by a CES utility function over a continuum of goods indexed by  $i \in \Omega$ :

$$X = \left[ \int_{i \in \Omega} (q_i x_i)^{\frac{\sigma-1}{\sigma}} di \right]^{\frac{\sigma}{\sigma-1}}, \quad (1)$$

where  $\sigma > 1$  is the elasticity of substitution and  $q_i$  denotes the quality of a product. The quality-adjusted price index is defined as:

$$P = \left[ \int_{i \in \Omega} \left( \frac{p_i}{q_i} \right)^{1-\sigma} di \right]^{\frac{1}{1-\sigma}}. \quad (2)$$

From the consumer's maximization problem follows that demand for one differentiated variety  $i$  increases in the quality level  $q_i$  and decreases in the price  $p_i$ :

$$x_i = q_i^{\sigma-1} X \left( \frac{p_i}{P} \right)^{-\sigma}. \quad (3)$$

By introducing a quality component in the utility function of the representative consumer (1), we follow the quality and trade literature.<sup>3</sup> Product quality  $q_i$  is endogenously chosen by producers and shifts demand outwards for any given price. Additionally, firms decide on the level of process innovations. The next two subsections describe optimal firm behavior in the presence of credit frictions.

### 3.2 Production and investment with credit constraints

The production sector of the economy is characterized by monopolistic competition. Each firm manufactures one differentiated variety  $i$  and decides on process and quality innovations that are both associated with endogenous sunk costs increasing in investment levels:

$$f(q_i) = \frac{1}{\kappa_i} q_i^\alpha; \quad g(e_i) = \frac{1}{\varphi_i} e_i^\beta. \quad (4)$$

Parameters  $\alpha$  and  $\beta$  determine the convexity of the investment cost functions and are exogenously given for producers in one sector. Hence,  $\frac{1}{\alpha}$  and  $\frac{1}{\beta}$  reflect the elasticities of quality and processes to innovation outlays. Low values of  $\alpha$  and  $\beta$  imply that one additional unit

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<sup>3</sup>See e.g. Baldwin and Harrigan (2011), Kugler and Verhoogen (2012), and Hallak and Sivadasan (2013).

of investment spending is very effective.<sup>4</sup> Producers differ in their capabilities to invest in process innovations  $\varphi_i$  and quality upgrades  $\kappa_i$ .<sup>5</sup> Higher values of these firm-specific draws scale down investment costs and hence increase incentives to innovate. The two types of innovation affect marginal production costs  $mc$  in opposite directions:

$$mc(q, e) = \frac{q^\theta}{e} \text{ with } 0 < \theta < 1. \quad (5)$$

The benefit of process innovations  $e$  is a reduction of marginal production costs which is closely related to the productivity draw in Melitz (2003). Quality innovations  $q$  increase demand for one variety (3), but are associated with higher labor requirements, where  $\theta$  describes the sensitivity of marginal costs to changes in quality. The positive relation between product quality and marginal production costs can be motivated by advertising expenditures or marketing. Related to our approach, other papers endogenize firm's quality choice and consider additional product-specific outlays or the use of higher-quality inputs.<sup>6</sup> As we allow for both cost-based and quality-based sorting with endogenous sunk costs, our model is closely related to Sutton (2007, 2012) and Hallak and Sivadasan (2013). Compared to previous work, we analyze the impact of credit conditions on two types of investment. Therefore, we assume that firms have to cover expenditures associated with endogenous innovations (4) by external capital before revenues are realized, whereas labor is used for variable and fixed production costs. The decision problem of a single firm consists of four stages:

1. **Entry stage.** A potential producer of a differentiated variety decides to enter the market and pays a fixed entry cost  $f_e$ . After entry, the firm draws both investment capabilities  $\varphi$  and  $\kappa$  from a joint probability distribution  $h(\varphi, \kappa)$  with positive support over  $[\underline{\varphi}, \bar{\varphi}] \times [\underline{\kappa}, \bar{\kappa}]$ .
2. **Financial contracting and investment.** Producers choose the optimal levels of process and quality innovations and sign a contract with an outside investor to cover the investment costs. Optimal prices are set.
3. **Moral hazard.** After financial contracting, the agent in the firm chooses to conduct the project diligently or to misbehave and reap a non-verifiable private benefit.
4. **Production and profit realization.** Production and profits are realized and the loan is repaid to the lender.

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<sup>4</sup>See Sutton (2012), section 1.10, for a comparable specification of quality outlays. In section 3.3, we impose a convexity assumption for technology parameters  $\alpha$  and  $\beta$ .

<sup>5</sup>For notational simplicity we drop the firm's index  $i$  in what follows.

<sup>6</sup>See Kugler and Verhoogen (2012) or Johnson (2012), among others.

Stages 2 and 3 introduce endogenous investment choices and financial frictions. Based on Holmstrom and Tirole (1997), we motivate credit constraints by a project choice which is non-verifiable for external investors and thus prone to moral hazard. The optimal contract between a firm and an outside investor specifies the loan size  $d_l > 0$  at a gross interest rate  $r > 1$ , and the credit repayment  $k_l$ , whereas the index  $l \in d, x$  denotes non-exporters ( $d$ ) and exporters ( $x$ ) respectively. We solve the model by backward induction. The next subsection describes optimal firm behavior after entry.

### 3.3 Optimal firm behavior

After entry, firms choose the optimal levels of process ( $e_l$ ) and quality innovations ( $q_l$ ) and set prices at home and possibly in the foreign market. Exporters sell their product to consumers in an identical foreign country, but face higher fixed costs  $f_x > f_d$ , and iceberg-type transportation costs such that  $\tau > 1$  units of a good have to be shipped for 1 unit to arrive. Whereas domestic and export prices of a firm differ because of transportation costs, we do not allow for market-specific investments. Hence, if a firm exports, the benefits of process and quality innovations are spread across sales in both destinations. Total sales of producers are defined as:  $s_l = p_l x_l + 1_{\{x_x^* > 0\}} p_x^* x_x^*$ , whereas demand is given by equation (3) and the dummy variable  $1_{\{x_x^* > 0\}}$  takes a value of 1 if the firm exports and is zero otherwise. Firms choose optimal investment levels and prices to maximize expected profits:

$$\max_{p_l, p_x^*, e_l, q_l} \lambda \pi_l = \lambda [s_l - mc(q_l, e_l) (x_l + 1_{\{x_x^* > 0\}} \tau x_x^*) - k_l] - f_l. \quad (6)$$

Variable profits net of loan repayment  $k_l$  realize with success probability  $0 < \lambda < 1$ . Firms use labor input for fixed and variable production costs, but have to finance innovation outlays by external capital. This assumption can be motivated by a time lag between investment activity and profit realization. Depending on their export status  $l \in d, x$ , firms face the following constraints:

$$d_l \geq \frac{1}{\kappa} q_l^\alpha + \frac{1}{\varphi} e_l^\beta, \quad (7)$$

$$\lambda k_l \geq r d_l, \quad (8)$$

$$\pi_l \geq 0. \quad (9)$$

The budget constraint (7) states that the received credit amount has to be sufficiently high to cover endogenous investment costs. Participation constraints (8) and (9) ensure that external investors do not incur losses from lending and firms make at least zero profits. We assume perfect competition in the financial sector such that equation (8) holds with equality.

Based on Holmstrom and Tirole (1997), we motivate credit frictions by moral hazard. After financial contracting and loan provision, the success of the investment depends on a non-verifiable project choice within the firm. On the one hand, the agent can decide to behave diligently and conduct the project properly which implies that profits realize with high success probability  $\lambda$ . On the other hand, if the agent chooses to misbehave, the probability of success is lower  $\lambda_b < \lambda$ , but the borrower can reap a share of fixed investments as a non-verifiable private benefit  $b f_l > 0$ . The manager faces incentives to implement the project in a more pleasant way or pursue own advantages at the expense of investment success. Following Tirole (2006), the private benefit can be interpreted as a disutility of effort.<sup>7</sup> Hence, both investment and entrepreneurial effort are inputs in the production process. There are no information asymmetries with respect to firm characteristics, but the project choice is non-contractible for external investors which leads to moral hazard. Shirking can be ruled out if the following incentive compatibility constraint holds:

$$\lambda \pi_l \geq \lambda_b \pi_l + b f_l. \quad (10)$$

We assume that the success probability  $\lambda_b$  is sufficiently low such that the net present value of the marginal firm which just meets incentive compatibility (10) is negative in case of shirking. Thus, the optimal financial contract has to satisfy incentive compatibility to rule out misbehavior and potential losses from lending. As long as the private benefit is positive, equation (10) is more restrictive than the zero-profit requirement (9). Hence, only firms that generate sufficiently high profits overcome moral hazard and have access to external finance. As private benefits are related to fixed costs, exporters face a trade-off between additional profits from selling abroad in case of diligent behavior and the prospect of higher perks in case of shirking. To describe the optimal behavior of firms, we proceed in two steps. First, conditional on access to finance, firms maximize expected profits (6) by taking into account constraints (7) and (8). Second, incentive compatibility (10) determines access to external capital and selection into exporting. Solving firm's maximization problem leads to the following optimal choices of process and quality innovations:<sup>8</sup>

$$e_l(\varphi, \kappa) = \left( \frac{\lambda A_l}{r} \right)^{\frac{\alpha}{\gamma}} \left( \frac{1-\theta}{\alpha} \kappa \right)^{\frac{(\sigma-1)(1-\theta)}{\gamma}} \left( \frac{\varphi}{\beta} \right)^{\frac{\alpha+(1-\theta)(1-\sigma)}{\gamma}}, \quad (11)$$

$$q_l(\varphi, \kappa) = \left( \frac{\lambda A_l}{r} \right)^{\frac{\beta}{\gamma}} \left( \frac{1-\theta}{\alpha} \kappa \right)^{\frac{\beta+1-\sigma}{\gamma}} \left( \frac{\varphi}{\beta} \right)^{\frac{\sigma-1}{\gamma}}, \quad (12)$$

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<sup>7</sup>See Tirole (2006), section 3.2, for a discussion of moral hazard in a simple model of credit rationing.

<sup>8</sup>See Appendix 8.1 for a detailed derivation of firm's maximization problem.

whereby  $\gamma \equiv \alpha\beta + (1 - \sigma)[\alpha + (1 - \theta)\beta]$ , and  $A_d \equiv XP^\sigma \left(\frac{\sigma-1}{\sigma}\right)^\sigma$ ,  $A_x \equiv (1 + \tau^{1-\sigma})A_d$  are measures of market size for domestic sellers and exporters respectively. Consistent with theoretical and empirical work on investment activity in international trade, our model suggests a positive relationship between innovation and market size.<sup>9</sup> As exporters spread investment costs across both markets, they face larger incentives to engage in quality and process innovations, ( $A_x > A_d$ ), whereas iceberg transportation costs  $\tau$  and the borrowing rate  $r$  reduce investment activity. We assume that investment costs are sufficiently convex:  $\alpha, \beta > (\sigma - 1)(2 - \theta)$ , such that  $\gamma > 0$ . The convexity assumption implies that quality and process innovations are complements and increase in both capabilities  $\varphi$  and  $\kappa$ . A higher capability draw for one type of innovation has a direct positive impact on the corresponding investment level due to lower endogenous sunk costs, and additionally increases the marginal benefit of the other innovation type. This complementary structure relates to the literature on simultaneous process and product R&D choices and is driven by the fact that both types of innovation increase the price-adjusted quality and hence the success of a firm in the market.<sup>10</sup> Consequently, producers will always engage in both types of innovation, whereas the relative investment in processes compared to quality improvements is given by:

$$\frac{e_l(\varphi, \kappa)}{q_l(\varphi, \kappa)} = \left(\frac{\lambda A_l}{r}\right)^{\frac{\alpha-\beta}{\gamma}} \left(\frac{1-\theta}{\alpha}\kappa\right)^{\frac{(\sigma-1)(2-\theta)-\beta}{\gamma}} \left(\frac{\varphi}{\beta}\right)^{\frac{\alpha+(2-\theta)(1-\sigma)}{\gamma}}. \quad (13)$$

The convexity assumption regarding endogenous sunk costs implies further that investments in process innovations relative to quality upgrades increase in the cost-based capability and decrease in the quality-based capability:  $\frac{\partial(\frac{e}{q})}{\partial\varphi} > 0$ ,  $\frac{\partial(\frac{e}{q})}{\partial\kappa} < 0$ . Additionally, the relative investment increases in  $\alpha$  and decreases in  $\beta$  as firms react to changes in the relative effectiveness of innovations. A higher sensitivity of marginal production costs with respect to quality (larger  $\theta$ ) reduces the marginal benefit of vertical product differentiation and increases the relative investment in processes. In the extreme case, if  $\theta = 1$ , higher quality leads to a one-to-one increase in marginal costs (5), such that marginal benefits of product upgrades and thus innovation choices (11) and (12) are driven down to zero.

Analogous to standard models with monopolistic competition and CES demand structure, firms set the optimal price as a constant markup over marginal costs. In contrast to Melitz (2003), marginal production costs are endogenously determined by the two innovation

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<sup>9</sup>See Bustos (2011) as well as Kugler and Verhoogen (2012), among others.

<sup>10</sup>Theoretical studies discuss complementarities between product and process innovations under different modes of market competition (Athey and Schmutzler, 1995; Lin and Saggi, 2002; Rosenkranz, 2003), as well as over the product life cycle (Klepper, 1996; Lambertini and Mantovani, 2010).

choices, whereas  $p_l$  denotes domestic prices of firms with export status  $l \in d, x$ :

$$p_l(\varphi, \kappa) = \frac{\sigma}{\sigma-1} \frac{q_l^\theta}{e_l} = \frac{\sigma}{\sigma-1} \left( \frac{r}{\lambda A_l} \right)^{\frac{\alpha-\beta\theta}{\gamma}} \left( \frac{1-\theta}{\alpha} \kappa \right)^{\frac{\beta\theta+1-\sigma}{\gamma}} \left( \frac{\beta}{\varphi} \right)^{\frac{\alpha-\sigma+1}{\gamma}}, \quad (14)$$

and  $p_x^*(\varphi, \kappa) = \tau p_x(\varphi, \kappa)$  stands for the export price of internationally active producers. The pricing rule captures two opposing effects of investment behavior. A higher level of process innovations enhances production efficiency, whereas quality innovations increase marginal costs according to equation (5). Consequently, the optimal price decreases in the cost-based capability  $\varphi$ , but increases in the quality-based capability  $\kappa$ .<sup>11</sup> Hence, the setup with two innovation choices captures both a negative relation between prices and firm size based on cost-based sorting à la Melitz (2003) and a positive correlation between prices and firm size as suggested by the recent quality and trade literature (e.g. Kugler and Verhoogen, 2012). The success of a producer in the market results from the ability to invest in processes as well as product quality at low costs. Therefore, we define firm's overall efficiency as a combination of both capabilities:  $z = \varphi^\alpha \kappa^{\beta(1-\theta)}$ . Figure 1 depicts an example for an iso-efficiency curve in the two-dimensional space, whereas the vertical axis shows the quality-based capability  $\kappa$  and the horizontal axis shows the cost-based capability  $\varphi$ . The curve represents a non-linear trade-off between the two attributes:  $\frac{\partial \kappa}{\partial \varphi} < 0$  and  $\frac{\partial^2 \kappa}{\partial \varphi^2} > 0$ . If a firm possesses a low ability to invest in processes (low  $\varphi$ ), it requires a relatively high quality-based capability  $\kappa$  to achieve the same overall efficiency level. Firms located along a particular iso-efficiency curve earn the same expected revenues and profits, since the latter can be expressed as monotone and increasing functions of efficiency  $z$ :

$$\lambda s_l(z) = \frac{\sigma}{\sigma-1} (\lambda A_l)^{\frac{\alpha\beta}{\gamma}} \left( r^{-\alpha-\beta(1-\theta)} \beta^{-\alpha} \left( \frac{1-\theta}{\alpha} \right)^{\beta(1-\theta)} z \right)^{\frac{\sigma-1}{\gamma}}, \quad (15)$$

$$\lambda \pi_l(z) = \frac{(\sigma-1)v}{\sigma} \lambda s_l(z) - f_l, \quad (16)$$

where  $v = \frac{1}{\sigma-1} - \left( \frac{1}{\beta} + \frac{1-\theta}{\alpha} \right) > 0$ . Comparable to single-attribute firm models, efficiency  $z$  is a one-dimensional measure of profits and firm size. However, producers with the same size or efficiency  $z$  choose different levels of quality and process innovations and thus set different prices, depending on their firm-specific capabilities. Revenues and profits depend positively on market size  $A_l$ , but negatively on the borrowing rate  $r$  and investment cost parameters

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<sup>11</sup>Elasticities of prices with respect to capabilities are given by:  $\frac{\partial p_l}{\partial \varphi} \frac{\varphi}{p_l} = \frac{\sigma-1-\alpha}{\gamma} < 0$  and  $\frac{\partial p_l}{\partial \kappa} \frac{\kappa}{p_l} = \frac{\beta\theta-\sigma+1}{\gamma} > 0$ , if  $\beta > \frac{\sigma-1}{\theta}$ . Note that this condition for the technology parameter  $\beta$  is more restrictive than the convexity assumption discussed earlier in this section.

$\alpha$  and  $\beta$ . Equations (11)-(16) characterize the optimal behavior of firms that have access to external finance. The next subsection takes into account incentive compatibility (10) which determines the selection of firms into exporting.

### 3.4 Selection of firms

Only firms that meet incentive compatibility (10) receive credit from outside investors. As profits (16) are a function of efficiency  $z$ , the binding financial constraint (10) determines a cutoff efficiency level that is necessary to obtain external finance:

$$z_l = \left(\frac{r}{\lambda}\right)^{\alpha+\beta(1-\theta)} \beta^\alpha \left(\frac{\alpha}{1-\theta}\right)^{\beta(1-\theta)} A_l^{\frac{-\alpha\beta}{\sigma-1}} \left(\frac{\Theta f_l}{v\lambda}\right)^{\frac{\gamma}{\sigma-1}}, \quad (17)$$

whereas  $\Theta = 1 + \frac{\lambda b}{\lambda - \lambda_b}$  reflects agency costs from moral hazard. Independent of export status, this measure captures financial frictions and determines the difference between the zero-profit condition (9) and incentive compatibility (10):

$$\frac{z_{ICC}}{z_{ZPC}} = \Theta^{\frac{\gamma}{\sigma-1}}. \quad (18)$$

If the private benefit  $b$  is equal to zero, financial frictions disappear and incentive compatibility collapses to a zero-profit condition ( $\Theta = 1$ ). Whenever the private benefit is positive ( $\Theta > 1$ ), moral hazard prevents external financing of profitable investment projects as some lower efficiency firms satisfy the zero-profit condition (9), but not incentive compatibility (10). Thus, financial imperfections impede market access of small producers which is consistent with existing heterogeneous firm models that allow for credit constraints (e.g. Manova, 2013). Note that Holmstrom and Tirole (1997) consider differences in wealth, whereas in our model firm-specific innovation capabilities determine access to external capital. Hence, we neglect the role of internal liquidity to overcome credit frictions as analyzed by Chaney (2013). If fixed  $f_x$  and variable trade costs  $\tau$  are sufficiently high, only the most capable firms select into exporting:

$$z_x > z_d \text{ if } \frac{f_x}{f_d} (1 + \tau^{1-\sigma})^{\frac{-\alpha\beta}{\gamma}} > 1. \quad (19)$$

This condition differs from Melitz (2003) because exporters spread expenditures associated with endogenous investments across sales in both markets.<sup>12</sup>

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<sup>12</sup>In Melitz (2003), a similar condition requires that  $\frac{f_x}{f_d} \tau^{\sigma-1} > 1$ .

**Proposition 1** *If Condition (19) holds, the most efficient firms with  $z \geq z_x$  export. Producers in the middle range of the efficiency distribution ( $z_d \leq z < z_x$ ) sell only domestically, while the least efficient firms ( $z < z_d$ ) have no access to external finance and exit.*

Graphically, equation (17) specifies the location of a marginal-access curve in the two-dimensional capability space  $(\varphi, \kappa)$ . Figure 2 depicts the selection pattern of firms under Proposition 1, whereby the marginal-access curve for exporting lies above the one for domestic activity.<sup>13</sup> Marginal firms, characterized by cutoff efficiencies  $z_d$  and  $z_x$ , just meet incentive compatibility (10) and are indifferent between diligent behavior and shirking, such that profits are equal to the probability-weighted private benefit:  $\pi(z_l) = \frac{bf_l}{\lambda - \lambda_b}$ . Additionally, revenues and investment expenditures of marginal producers are independent of capabilities and depend on fixed parameters only:

$$s_l(z_l) = \frac{\sigma \Theta f_l}{(\sigma - 1) v \lambda}, \quad (20)$$

$$\frac{1}{\varphi} e_l^\beta(z_l) = \frac{\Theta f_l}{c v r}; \quad \frac{1}{\kappa} q_l^\alpha(z_l) = \frac{(1 - \theta) \Theta f_l}{\alpha v r}. \quad (21)$$

These expressions for marginal firms are obtained by combining optimal innovation choices (11) and (12) with the cutoff efficiency levels (17). An increase in the private benefit  $b$  aggravates moral hazard and requires a higher cutoff efficiency level (17) to meet incentive compatibility (10), resulting in exit of low capability firms. Graphically, marginal-access curves in Figure 2 shift upwards. Similar selection effects occur if fixed production costs go up. Furthermore, the cutoff level (17) increases in technology cost parameters  $\alpha$  and  $\beta$ , and decreases in market size  $A_l$ . Whereas the private benefit imposes an access barrier to external finance and affects the extensive margin, a change in credit costs induces within-firm adjustments. The impact of credit conditions can be interpreted in a slightly different way: capital market imperfections impose minimum quality requirements. To see this, we follow Sutton (2012) and derive the quality-price ratio that reflects the effective competitiveness of a firm.<sup>14</sup>

$$\frac{q_l}{p_l} = \frac{\sigma - 1}{\sigma} \left( \left( \frac{\lambda A_l}{r} \right)^{\alpha + \beta(1 - \theta)} \beta^{-\alpha} \left( \frac{1 - \theta}{\alpha} \right)^{\beta(1 - \theta)} z \right)^{\frac{1}{\gamma}}. \quad (22)$$

Like revenues and profits, the quality-price ratio is an increasing function of both innovation choices and thus of firm's efficiency  $z$ , as depicted in Figure 3. Whereas process innovations decrease prices for any given quality, product upgrades increase quality for any given

<sup>13</sup>The two-dimensional selection pattern is closely related to Sutton (2007).

<sup>14</sup>Compare Sutton (2012), chapter 1.6.

price. Faced with higher borrowing rates, firms scale down both types of innovation resulting in a lower quality-price ratio. Graphically, within-firm adjustments correspond to a downward shift of the quality-price profile depicted in Figure 3 for two different borrowing rates:  $r_1 < r_2$ . While this effect negatively influences the intensive margin of international trade, credit frictions affect the extensive margin. The horizontal line represents a minimum quality requirement that is necessary to obtain external capital. This threshold is derived by inserting the cutoff efficiency level (17) in equation (22). An increase in the private benefit raises the cutoff efficiency level and hence the minimum quality requirement reflected in an upward shift of the horizontal line in Figure 3, whereas within-firm adjustments and hence changes in the individual price-adjusted quality are not present. The remainder of the paper discusses the implications of within-firm adjustments and selection effects in partial and general equilibrium. Consistent with recent empirical evidence, the following section shows that reoptimizations of innovation choices can explain positive as well as negative correlations of credit costs with export prices, depending on the scope for vertical product differentiation. In chapters 5 and 6, we analyze the general equilibrium effects of credit tightening.

## 4 Quality and cost effects in partial equilibrium

This section analyzes how firms respond to changes of credit conditions in partial equilibrium, whereby the number of firms and the cutoff efficiency level remains unchanged. Hence, results of this analysis could be interpreted as short-term effects of credit tightening. Furthermore, the interest rate  $r$  is treated as exogenous, whereas section 5 takes into account general equilibrium effects and endogenizes the borrowing rate by capital market clearing. An increase in the borrowing rate  $r$  leads to negative effects on both process innovations (11) and quality investments (12):

$$\frac{\partial e_l(\varphi, \kappa)}{\partial r} \frac{r}{e_l(\varphi, \kappa)} = -\frac{\alpha}{\gamma} < 0 ; \quad \frac{\partial q_l(\varphi, \kappa)}{\partial r} \frac{r}{q_l(\varphi, \kappa)} = -\frac{\beta}{\gamma} < 0 . \quad (23)$$

A reduction in the success probability  $\lambda$  leads to the same within-firm adjustments as it increases the rate of return demanded by external investors. Reductions in both types of investment influence marginal costs (5) and hence optimal price setting in opposite ways. On the one hand, firms scale down process innovations resulting in lower production efficiency and increased marginal costs. As equation (14) shows, this cost effect pushes optimal prices up. On the other hand, producers reduce product investments which leads to an opposing quality effect and dampens prices. The relative importance of quality and cost effects depends on the scope for vertical product differentiation in the production sector.

**The scope for vertical product differentiation.** Following Sutton (2001) as well as Kugler and Verhoogen (2012), we define this measure as the ratio of expenditures for quality innovations relative to firm revenues:

$$\frac{\frac{1}{\kappa} q_l^\alpha(z)}{s_l(z)} = \frac{(\sigma - 1)(1 - \theta)}{\alpha \sigma r}. \quad (24)$$

As equation (24) shows, the scope for product differentiation is independent of firm-specific capabilities, but increases in the elasticity of substitution  $\sigma$  and decreases in the borrowing rate  $r$ . Furthermore, quality differentiation is lower if investment costs become more convex (higher  $\alpha$ ) and the sensitivity of marginal costs to quality increases (higher  $\theta$ ). A similar measure expresses the scope for process innovations relative to firm size:

$$\frac{\frac{1}{\varphi} e_l^\beta(z)}{s_l(z)} = \frac{\sigma - 1}{\beta \sigma r}. \quad (25)$$

Increased product market competition (higher  $\sigma$ ) has a positive effect on process intensity, whereas the borrowing rate  $r$  as well as convexity of investment costs  $\beta$  lower innovation expenditures relative to firm revenues. The combination of equations (24) and (25) describes the relative scope for vertical product differentiation, compared to process innovations, as a constant ratio of technology parameters:

$$\frac{\frac{1}{\kappa} q_l^\alpha(z)}{\frac{1}{\varphi} e_l^\beta(z)} = \frac{(1 - \theta) \beta}{\alpha}. \quad (26)$$

Increases in  $\alpha$  and  $\theta$  make quality innovations less effective and reduce the relative expenditures for this investment type. Conversely, the ratio increases in  $\beta$ , which changes investment in favor of product upgrades. Hence, expression (26) reflects the relative effectiveness of quality innovations compared to process innovations and is closely related to the estimation of quality ladders proposed by Khandelwal (2010). In sectors with higher relative effectiveness, firms engage more in vertical product differentiation resulting in a larger demand shifter  $q$ . Following Khandelwal (2010), higher consumer's valuation for quality, conditional on prices, translates into larger market volumes and represents a proxy for a market's quality ladder. The relative scope for vertical product differentiation (26) determines how relative investment (13) and prices (14) respond to an increase in the borrowing rate:

$$\frac{\partial \left( \frac{e_l}{q_l} \right)}{\partial r} \frac{r q_l}{e_l} = \frac{\beta - \alpha}{\gamma}; \quad \frac{\partial p_l}{\partial r} \frac{r}{p_l} = \frac{\alpha - \beta \theta}{\gamma}. \quad (27)$$

**Proposition 2** *If the scope for vertical product differentiation is relatively high (low) and hence  $\alpha < (>) \beta$ , firms respond to higher credit costs by decreasing (increasing) the quality of their products relative to cost-based productivity and set lower (higher) prices.*

Consistent with recent empirical evidence, our model rationalizes positive as well as negative relations of firm-level FOB prices with credit costs, depending on the role of quality differentiation in a sector. Secchi et al. (2014) exploit Italian firm-level data and find that financially constrained exporters charge higher prices than unconstrained firms within the same product-destination market. This positive relationship between credit frictions and prices points to cost effects, but is reduced for product categories with high quality differentiation. Following Kugler and Verhoogen (2012), Secchi et al. (2014) use the ratio of advertising and R&D expenditures to total sales in U.S. industries as a proxy for vertical product differentiation. Hence, the measure is comparable to expression (24) in our theoretical model. Closely related, Fan et al. (2015) analyze Chinese firm-level data and find evidence for a negative relationship between credit frictions and prices. The authors rationalize this result by a partial equilibrium model based on Arkolakis (2010) and Manova (2013) and differentiate between exogenous and endogenous quality. Fan et al. (2015) show that constrained firms sell at higher prices when quality is exogenous, whereas the opposite holds in case of endogenous quality choice. In contrast, our model explains the prevalence of quality and cost effects when firms endogenously choose two innovation types that affect marginal production costs in opposite ways. Therefore, we reconcile recent empirical evidence and stress the role of vertical product differentiation for counteracting cost and quality effects on prices.

**Trade liberalization.** Comparable to changes in credit costs, trade liberalization leads to opposing quality and costs effects on FOB prices of exporters. A reduction in variable trade costs  $\tau$  induces exporters to invest more both in process and quality innovations shown by the following elasticities:<sup>15</sup>

$$\frac{\partial e_x}{\partial \tau} \frac{\tau}{e_x} = \frac{\alpha(1-\sigma)}{\gamma} \frac{\tau^{1-\sigma}}{1+\tau^{1-\sigma}} < 0; \quad \frac{\partial q_x}{\partial \tau} \frac{\tau}{q_x} = \frac{\beta(1-\sigma)}{\gamma} \frac{\tau^{1-\sigma}}{1+\tau^{1-\sigma}} < 0. \quad (28)$$

Analogous to credit shocks, the relative scope for vertical product differentiation determines the adjustment of the relative investment and hence the direction of price changes:<sup>16</sup>

$$\frac{\partial \left( \frac{e_x}{q_x} \right)}{\partial \tau} \frac{\tau q_x}{e_x} = \frac{(\alpha - \beta)(1 - \sigma)}{\gamma} \frac{\tau^{1-\sigma}}{1 + \tau^{1-\sigma}}; \quad \frac{\partial p_x}{\partial \tau} \frac{\tau}{p_x} = \frac{(\alpha - \beta\theta)(\sigma - 1)}{\gamma} \frac{\tau^{1-\sigma}}{1 + \tau^{1-\sigma}}. \quad (29)$$

<sup>15</sup>The derivatives follow immediately from equations (11) and (12).

<sup>16</sup>Compare the expression for relative investment (13) and optimal price setting (14).

**Proposition 3** *If the scope for vertical product differentiation is relatively high (low), such that  $\alpha < (>) \beta$ , trade liberalization leads to an increase (decrease) of product quality compared to cost-based efficiency and higher (lower) FOB prices:  $\frac{\partial(\frac{c_x}{q_x})}{\partial\tau} > (<) 0$ ;  $\frac{\partial p_x}{\partial\tau} < (>) 0$ .*

If the degree of vertical differentiation is high, product quality increases more than cost-based productivity leading to upward pressure on marginal costs and prices. Conversely, if the industry is characterized by low product differentiation, increases in process innovations and thus the cost reducing effect dominate and lead to negative price reactions. Consistent with these predictions, Fan et al. (2014) show for Chinese firm-level data that tariff reductions induce quality upgrading of exporters resulting in positive or negative price reactions, depending on whether the degree of vertical product differentiation is high or low. To rationalize this result, the authors extend a Melitz-type partial equilibrium model by endogenous quality choice. Faced with trade liberalization, firms readjust product quality by solving a trade-off between increases in demand due to higher quality and decreases in sales due to higher prices. In contrast, our model shows that trade and credit costs influence prices at the firm level through endogenous adjustments of quality and process innovations.

In addition to this partial equilibrium scenario, we analyze the general equilibrium effects of credit tightening. Considering the selection of firms, the scope for vertical product differentiation does not only determine the direction of within-firm adjustments, but also influences the role of quality sorting and cost-based productivity sorting in our model with two sources of firm heterogeneity. Graphically, the slope of the marginal-access curve in the two-dimensional capability space is the negative inverse of measure (26):  $\frac{d \ln \kappa}{d \ln \varphi} = -\frac{\alpha}{\beta(1-\theta)}$ . Hence, sectors with higher quality differentiation are characterized by flatter marginal-access curves (see Figure 4) and a negative relationship between credit costs and prices. In this case, access to finance is mainly determined by a minimum requirement on the quality-based capability and our model is closely related to single-attribute frameworks that focus on quality sorting (e.g. Baldwin and Harrigan, 2011; Kugler and Verhoogen, 2012). Consistent with recent empirical evidence, prices and firm size are positively correlated if the scope for vertical product differentiation is high (e.g. Manova and Zhang, 2012). Larger firms with higher quality-based capability  $\kappa$  invest more in quality upgrades resulting in higher prices:

$$\frac{\partial p_i \kappa}{\partial \kappa p_i} = \frac{\beta\theta - \sigma + 1}{\gamma} > 0.^{17}$$

In contrast, if the scope for vertical differentiation is low, marginal-access curves become steeper and the model resembles a Melitz (2003) - type economy with cost-based sorting. In sectors with low quality differentiation, empirical studies point to a negative relation of firm size and productivity with unit values (Roberts and Supina, 1996; Foster et al.,

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<sup>17</sup>See the pricing rule (14) and Footnote 11.

2008). Accordingly, larger firms with higher cost-based capability  $\varphi$  invest more in process innovations that reduce marginal costs and prices:  $\frac{\partial p_l}{\partial \varphi} \frac{\varphi}{p_l} = \frac{\sigma-1-\alpha}{\gamma} < 0$ . In this case, financial shocks induce mainly cost effects resulting in a positive relationship between credit costs and optimal prices. To analyze the effects of credit tightening on aggregate export performance and firm selection, the next section presents the general equilibrium.

## 5 Equilibrium in the open economy

At the entry stage, firms draw both investment capabilities  $\varphi$  and  $\kappa$  from a joint probability distribution  $h(\varphi, \kappa)$  with positive support over  $[\underline{\varphi}, \bar{\varphi}] \times [\underline{\kappa}, \bar{\kappa}]$ . As described in section 3.3, we summarize these two capabilities in a single measure of firm's efficiency:  $z = \varphi^\alpha \kappa^{\beta(1-\theta)}$ . The marginal-access cutoff levels (17) define regions in the two-dimensional capability space  $(\varphi, \kappa)$ , as depicted in Figure 2:

$$D = \{(\varphi, \kappa) \in [\underline{\varphi}, \bar{\varphi}] \times [\underline{\kappa}, \bar{\kappa}] : z \geq z_d\}, \quad (30)$$

$$D_d = \{(\varphi, \kappa) \in [\underline{\varphi}, \bar{\varphi}] \times [\underline{\kappa}, \bar{\kappa}] : z_d \leq z < z_x\}, \quad (31)$$

$$D_x = \{(\varphi, \kappa) \in [\underline{\varphi}, \bar{\varphi}] \times [\underline{\kappa}, \bar{\kappa}] : z \geq z_x\}, \quad (32)$$

where  $D$  is the set of all active firms in equilibrium and  $D_l$ , with  $l \in d, x$ , denotes regions of domestic producers and exporters respectively. Ex-ante probabilities of being active in one particular region  $\chi_l$  as well as the probability of success  $\chi_s$  are defined as:

$$\chi_l = \int \int_{(\varphi, \kappa) \in D_l} h(\varphi, \kappa) d\varphi d\kappa; \quad \chi_s = \int \int_{(\varphi, \kappa) \in D} h(\varphi, \kappa) d\varphi d\kappa, \quad (33)$$

and corresponding conditional probabilities are given by  $\mu_s(\varphi, \kappa) = \frac{h(\varphi, \kappa)}{\chi_s}$  and  $\mu_l(\varphi, \kappa) = \frac{h(\varphi, \kappa)}{\chi_l}$ . For aggregation purposes we define the average efficiency within each group:

$$\tilde{z}_l^{\frac{\sigma-1}{\gamma}} = \int \int_{(\varphi, \kappa) \in D_l} z^{\frac{\sigma-1}{\gamma}}(\varphi, \kappa) \mu_l(\varphi, \kappa) d\varphi d\kappa. \quad (34)$$

Average revenues and expected profits by group of non-exporters and exporters can be expressed as:

$$\tilde{s}_l = \int \int_{(\varphi, \kappa) \in D_l} s_l(\varphi, \kappa) \mu_s(\varphi, \kappa) d\varphi d\kappa, \quad (35)$$

$$E\pi_l = \int \int_{(\varphi, \kappa) \in D_l} \lambda \pi_l(\varphi, \kappa) \mu_s(\varphi, \kappa) d\varphi d\kappa. \quad (36)$$

Analogous to Melitz (2003), revenues of a particular firm with efficiency  $z$  can be expressed relative to the marginal domestic seller or exporter, characterized by the cutoff level  $z_l$ :

$$s_l(z) = \left( \frac{z}{z_l} \right)^{\frac{\sigma-1}{\gamma}} s_l(z_l). \quad (37)$$

As discussed in section 3.4, revenues of marginal firms depend only on fixed parameters of the model. By taking into account expression (20) and the definition of average efficiency (34), we write expected revenues and profits by group as follows:

$$\lambda \tilde{s}_l = \frac{\sigma \Theta f_l}{(\sigma - 1) v} \left( \frac{\tilde{z}_l}{z_l} \right)^{\frac{\sigma-1}{\gamma}}; \quad E\pi_l = \frac{(\sigma - 1) v}{\sigma} \lambda \tilde{s}_l - f_l. \quad (38)$$

The equilibrium is determined by equation (38) and a free entry condition to ensure that fixed entry costs  $f_e$  are equal to expected profits before firms know their capability draws:

$$E\pi = \frac{\delta f_e}{\chi_s}, \quad (39)$$

whereas  $\delta$  is the exogenous probability of a death shock. Total expected profits are the weighted sum of profits by group:  $E\pi = \sum_l \psi_l E\pi_l$ , whereby the share of producers in one group is defined as  $\psi_l = \frac{\chi_l}{\chi_s}$ . Equations (38) and (39) determine the minimum efficiency of marginal firms  $z_d$  that are just able to produce for the domestic market. The general equilibrium is characterized by two additional conditions. Labor market clearing pins down the number of active firms  $M$  in the economy and capital market clearing determines the interest rate  $r$ . Labor requirements of single firms consist of variable and fixed production costs and can be expressed as functions of revenues:

$$mc_l(\varphi, \kappa) [x_l(\varphi, \kappa) + 1_{\{x_x^* > 0\}} \tau x_x^*(\varphi, \kappa)] + f_l = \frac{\sigma - 1}{\sigma} s_l(z) + f_l. \quad (40)$$

Producers with higher efficiency  $z$  employ more labor due to increased investment expenditures and larger sales. In equilibrium, the inelastic labor supply  $L$  has to be equal to labor demands in the entry sector ( $L_e = M_e f_e$ ) and of the two groups of active producers:  $L = L_e + \sum_l L_l$ . Analogous to Melitz (2003), aggregation of single labor requirements pins

down the mass of active firms  $M$  in one country:

$$M = \frac{L}{\lambda \tilde{s} \left[ 1 - \frac{\sigma-1}{\sigma} \left( \frac{1}{\beta} + \frac{1-\theta}{\alpha} \right) \right]}, \quad (41)$$

where  $\tilde{s} = \sum_l \psi_l \tilde{s}_l$  denotes average revenues in the total economy. This relationship is obtained by imposing aggregate stability such that the mass of successful entrants is equal to the mass of firms that are forced to exit due to the exogenous death shock:  $\chi_s M_e = \delta M$ . The aggregate demand for capital by group consists of investment expenditures for process and quality innovations:

$$M_l \int \int_{(\varphi, \kappa) \in D_l} \frac{1}{\varphi} e_l^\beta(\kappa, \varphi) \mu_l(\varphi, \kappa) d\varphi d\kappa = \frac{\sigma-1}{\beta \sigma r} M \lambda \tilde{s}_l, \quad (42)$$

$$M_l \int \int_{(\varphi, \kappa) \in D_l} \frac{1}{\kappa} q_l^a(\varphi, \kappa) \mu_l(\varphi, \kappa) d\varphi d\kappa = \frac{(\sigma-1)(1-\theta)}{\alpha \sigma r} M \lambda \tilde{s}_l. \quad (43)$$

More convex investment costs (higher  $\alpha$  and  $\beta$ ) as well as a higher borrowing rate  $r$  scale down process and quality innovations which leads to lower capital demand. Aggregate investment expenditures for processes and quality upgrades are functions of average revenues and the number of firms in the market. The ratio of aggregate investment expenditures leads to the sectoral scope for vertical product differentiation (26) that is independent of firm capabilities, as discussed in section 4. Capital market clearing ensures that aggregate capital demand for both innovation types equals capital supply  $K$ :

$$K = \frac{\sigma-1}{\sigma r} \left( \frac{1-\theta}{\alpha} + \frac{1}{\beta} \right) M \lambda \tilde{s}. \quad (44)$$

Combining the market clearing conditions for labor (41) and capital (44) uniquely determines the equilibrium interest rate:

$$r = \frac{\frac{\sigma-1}{\sigma} \left( \frac{1}{\beta} + \frac{1-\theta}{\alpha} \right) L}{1 - \frac{\sigma-1}{\sigma} \left( \frac{1}{\beta} + \frac{1-\theta}{\alpha} \right) K}. \quad (45)$$

The interest rate decreases in the investment cost parameters  $\alpha, \beta$  and  $\theta$  as well as in capital supply  $K$  and increases with product market competition captured by the elasticity of substitution  $\sigma$ . In the following two sections, we exploit general equilibrium properties of the model to derive aggregate effects and welfare implications of credit tightening.

## 6 Effects of credit tightening in general equilibrium

In general equilibrium, we take into account that credit frictions change the number of active producers in the sector. To derive explicit solutions of aggregate variables, we assume that capabilities  $\varphi$  and  $\kappa$  are independently Pareto distributed with positive support over  $[1, \bar{\varphi}] \times [1, \infty]$  and  $\bar{\varphi} > 1$ . The probability of drawing a particular combination of  $\varphi$  and  $\kappa$  is given by:  $h(\varphi, \kappa) = h_\varphi(\varphi)h_\kappa(\kappa)$  with  $h_\kappa(\kappa) = \xi\kappa^{-\xi-1}$  and  $h_\varphi(\varphi) = \vartheta\frac{\varphi^{-\vartheta-1}}{1-\bar{\varphi}^{-\vartheta}}$ , where  $\xi$  and  $\vartheta$  are the shape parameters of the Pareto distributions.<sup>18</sup> As we consider two symmetric countries, our general equilibrium analysis neglects implications of bilateral differences in financial development or in credit conditions. In contrast, another strand of literature examines how national differences in financial characteristics influence cross-border trade and capital flows (see Antràs and Caballero, 2009; Furusawa and Yanagawa, 2010, among others). The next subsection shows how financial shocks affect optimal investment and pricing behavior in general equilibrium and compares the results to the partial equilibrium analysis in section 4. Subsection 6.2 discusses the welfare effects of credit tightening.

	Partial equilibrium				General equilibrium			
Financial shock	$r \uparrow / \lambda \downarrow$		$b \uparrow$		$r \uparrow$		$\lambda \downarrow / b \uparrow$	
Vertical differentiation	low	high	low	high	low	high	low	high
Process $e$ / quality innovation $q$	-		0		-		+	
Relative investment $\frac{e}{q}$	-	+	0		-	+	+	-
Price $p$	+	-	0		+	-	-	+

Table 1: Financial shocks and optimal firm behavior in partial and general equilibrium

### 6.1 Effects on investment and price setting

Table 1 summarizes the optimal responses to financial shocks in partial and general equilibrium. The main result of this section is that stronger credit frictions (an increase in  $b$  or a decrease in  $\lambda$ ) reduce the competitive pressure in general equilibrium and reverse the direction of within-firm adjustments. In contrast, an increase in the interest rate does not reflect stronger credit frictions, but could be caused by a decrease in aggregate capital supply  $K$ , and has no effect on the extensive margin:<sup>19</sup>

$$\frac{\partial M}{\partial r} \frac{r}{M} = 0; \quad \frac{\partial z_d}{\partial r} \frac{r}{z_d} = 0. \quad (46)$$

<sup>18</sup>For technical reasons, we assume that  $\xi > \frac{\beta(1-\theta)(\sigma-1)}{\gamma}$  and  $\vartheta > \frac{\alpha\xi}{\beta(1-\theta)}$ . Appendix 8.3 derives the cutoff efficiency  $z_d$  explicitly under the assumption of Pareto distributed capabilities.

<sup>19</sup>Compare the capital market clearing condition in general equilibrium (45).

This result depends on the assumption that only endogenous investment costs have to be financed by external capital, whereas labor input is used for fixed production costs. As Table 1 shows, optimal firm responses to an increase in the borrowing rate  $r$  go into the same direction in partial and general equilibrium. If fixed costs have to be financed by external capital, exit of low efficiency firms would raise the cutoff efficiency. Consequently, increased competitive pressure would even amplify the responses in general equilibrium without changing the direction of the effects.<sup>20</sup>

**Proposition 4** *An increase in the borrowing rate  $r$  has no effect on the extensive margin, whereas within-firm adjustments go into the same direction in partial and general equilibrium.*

In contrast to an increase in borrowing costs  $r$ , stronger credit frictions change the direction of optimal firm responses in general equilibrium. The private benefit  $b$  can be interpreted as an inverse measure of financial development which might be affected by countries' financial policies. Following Tirole (2006) and Antràs, Desai, and Foley (2009), this managerial benefit of shirking might be reduced by improved investor protection or stronger enforceability of financial contracts. An increase in the private benefit  $b$  enhances incentives of borrowers to misbehave such that external investors demand more pledgeable income to provide loans for investment. A decrease in the success probability of investment projects  $\lambda$  increases the rate of return required for investors to break even and aggravates moral hazard. Consequently, both shocks impose stronger restrictions on incentive compatibility (10) resulting in exit of low efficiency firms:<sup>21</sup>

$$\frac{\partial M}{\partial b} \frac{b}{M} = -\frac{\lambda b}{\Delta\lambda + \lambda b} < 0; \quad \frac{\partial z_d}{\partial b} \frac{b}{z_d} > 0, \quad (47)$$

$$\frac{\partial M}{\partial \lambda} \frac{\lambda}{M} = \frac{\lambda b}{\Delta\lambda + \lambda b} \frac{\lambda_b}{\Delta\lambda} > 0; \quad \frac{\partial z_d}{\partial \lambda} \frac{\lambda}{z_d} < 0. \quad (48)$$

whereas  $\Delta\lambda = \lambda - \lambda_b$ . Compared to partial equilibrium, the exit of low efficiency producers leads to additional firm adjustments in case of an increase in  $b$  and reverses the responses to a decrease in  $\lambda$  (see Table 1). This general equilibrium effect reduces the competitive pressure in the sector and induces still active suppliers to increase innovation activity. Intuitively, the negative effect of credit frictions along the extensive margin enhances the benefits of investments for existing firms. Thus, stronger credit frictions lead to an equilibrium with a lower number of producers that are larger on average. This effect is counteracted by an increase in the cutoff efficiency which reduces, but does not outweigh the positive response of innovation activity.

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<sup>20</sup>See Appendix 8.5 for an extension of the model by external financing of fixed costs.

<sup>21</sup>See Appendix 8.3 for an explicit derivation of the number of firms in one country.

**Proposition 5** *In general equilibrium, stronger credit frictions (an increase in the private benefit  $b$  or a reduction in the success probability  $\lambda$ ) reduce the number of active producers, raise the cutoff efficiency  $z_d$ , and increase innovation activity as well as firm size of existing suppliers.*

**Proof.** See Appendix 8.4. ■

In contrast to partial equilibrium, stronger financial frictions lead to a reduction of prices in sectors with low quality differentiation. Thus, credit tightening intensifies quality-based (cost-based) sorting if the scope for vertical differentiation is high (low). The next subsection discusses the welfare consequences of financial shocks.

## 6.2 Welfare analysis

Analogous to Melitz (2003), we derive consumer welfare as a positive function of the cutoff efficiency level  $z_d$ .<sup>22</sup>

$$W = \frac{\sigma - 1}{\sigma} \left(\frac{1}{\beta}\right)^{\frac{1}{\beta}} \left(\frac{1 - \theta}{\alpha}\right)^{\frac{1 - \theta}{\alpha}} \left(\frac{1}{r}\right)^{\frac{\alpha + \beta(1 - \theta)}{\alpha\beta}} \left(\frac{v}{\Theta f_d}\right)^{\frac{\gamma}{\alpha\beta(\sigma - 1)}} \left(\frac{L}{1 + v}\right)^{\frac{1}{\sigma - 1}} z_d^{\frac{1}{\alpha\beta}}. \quad (49)$$

An increase in the borrowing rate  $r$  leads to negative effects on process and quality innovations (see section 4) resulting in welfare losses along the intensive margin:

$$\frac{\partial W}{\partial r} \frac{r}{W} = -\frac{\alpha + \beta(1 - \theta)}{\alpha\beta} < 0. \quad (50)$$

**Proposition 6** *An increase in the borrowing rate  $r$  leads to negative effects along the intensive margin and welfare losses that are stronger in sectors with high investment intensity.*

Elasticity (50) shows that negative welfare effects become more pronounced with increasing quality differentiation (24) and process intensity (25), when technology parameters  $\alpha$ ,  $\beta$  and  $\theta$  are low. Hence, an increase in credit costs leads to greater adjustments of innovation activity in sectors with high investment intensity. Consequently, consumers face a stronger decrease in price-adjusted quality resulting in larger welfare losses.

As discussed in the previous subsection, stronger credit frictions cause negative effects along the extensive margin. The exit of least efficient firms leads to two opposing effects on consumer welfare (49). On the one hand, welfare decreases due to a lower number of varieties. On the other hand, the average efficiency, and thus the average price-adjusted

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<sup>22</sup>See Appendix 8.2 for a derivation of the welfare function.

quality offered in the economy, increases ( $\frac{\partial z_d}{\partial b} > 0$ ;  $\frac{\partial z_d}{\partial \lambda} < 0$ ). The effects of credit tightening on consumer welfare are given by:

$$\frac{\partial W}{\partial b} \frac{b}{W} = -\frac{1}{\alpha\beta} \left( \frac{\gamma}{\sigma-1} \frac{\lambda b}{\Delta\lambda + \lambda b} - \frac{\partial z_d}{\partial b} \frac{b}{z_d} \right) < (>) 0, \quad (51)$$

$$\frac{\partial W}{\partial \lambda} \frac{\lambda}{W} = \frac{1}{\alpha\beta} \left( \frac{\gamma\lambda_b}{\Delta\lambda(\sigma-1)} \frac{\lambda b}{\Delta\lambda + \lambda b} + \frac{\partial z_d}{\partial \lambda} \frac{\lambda}{z_d} \right) < (>) 0. \quad (52)$$

**Proposition 7** *Stronger credit frictions (an increase in the private benefit  $b$  or a reduction in the success probability  $\lambda$ ) reduce consumer welfare if the private benefit  $b$  is sufficiently high. Welfare losses are more pronounced in sectors with low investment intensity (high  $\alpha$  and/or  $\beta$ ).*

**Proof.** See Appendix 8.4. ■

If financial development is low (captured by a high private benefit  $b$ ), stronger credit frictions will lead to a large reduction in product variety that outweighs efficiency gains. Proposition 7 shows that the extent of welfare losses after credit tightening depends on the sectoral investment intensity. An increase in the borrowing rate leads to a larger reduction in consumer welfare in sectors with high investment intensity due to stronger within-firm adjustments (see Proposition 6). In contrast, changes in the private benefit  $b$  and the success probability  $\lambda$  lead to a negative impact along the extensive margin which affects sectors with low investment intensity more severely. The reason is that consumers in those sectors put more weight on the loss of variety compared to efficiency gains due to the exit of firms. Figure 5 illustrates the larger welfare responses to an increase in  $b$  for sectors with high levels of investment cost parameters  $\alpha$  and  $\beta$  (see Table 2 for chosen parameter values). The negative variety effect and thus welfare losses are more pronounced if financial development is low (high private benefit) and dispersion of firm capabilities is high (larger values for Pareto shape parameters). If the distribution of firms in the efficiency space is more dispersed, efficiency gains after firm exit will be lower, which results in stronger reactions of welfare.

Thus, the comparative static analysis shows that the effects of financial shocks within a sector depend on the investment intensity and the role of quality differentiation. Both in partial and general equilibrium, the scope for vertical differentiation (26) determines how optimal investment and pricing behavior is affected by credit conditions. Furthermore, aggregate effects of credit tightening depend on the sectoral investment intensity for quality (24) and processes (25). Interest rate shocks lead to adjustments along the intensive margin and especially hurt sectors with high investment intensity. Stronger credit frictions affect the extensive margin of international trade, whereas sectors with low investment intensity face larger welfare losses.

## 7 Conclusion

This paper has analyzed the effects of credit frictions on within-firm adjustments and selection into exporting in a two-dimensional heterogeneous firm model with endogenous innovation choices. Whereas existing trade models with financial frictions are mainly based on Melitz (2003), three elements are crucial for our theoretical analysis. First, we allow both for Melitz-type cost sorting and vertical product differentiation. Like in single-attribute models, firm's competitiveness and hence profits are determined by a one-dimensional productivity measure. The latter can be separated along two dimensions, namely the cost-based and the quality-based capability of a producer. Second, we consider innovations in quality and processes associated with endogenous sunk costs that decrease in capabilities. Third, we assume that investment costs have to be financed by external investors and introduce credit constraints motivated by moral hazard based on Holmstrom and Tirole (1997).

We show that the scope for vertical product differentiation in a sector determines how financial shocks affect investment and price setting. Consistent with recent empirical evidence, we rationalize positive as well as negative correlations of FOB prices with credit frictions and variable trade costs. In addition, we distinguish the effects of financial frictions in partial and general equilibrium. In partial equilibrium, which could be interpreted as a short-term scenario, the number of suppliers is fixed and credit tightening leads to negative effects on investment. In general equilibrium, stronger credit frictions intensify quality-based (cost-based) sorting of firms if the scope for vertical product differentiation is high (low). Consequently, credit tightening leads to firm exit, increased innovation activity among existing suppliers and welfare losses that are larger in sectors with low investment intensity.

Our theoretical analysis could be extended in several directions. First, we do not allow for market-specific investments. Both process innovations and quality upgrades are spread across domestic and foreign markets, whereas recent empirical evidence points to quality-based market segmentation of exporters (Bastos and Silva, 2010; Manova and Zhang, 2012; Flach, 2014). Second, suppliers rely on one source of external capital to finance total investment costs. This allows us to focus on within-firm adjustments, whereas selection effects between different sources of external finance might play an important role as well (see Hou and Zhang, 2012). Third, whereas our analysis focuses on a CES demand structure, credit frictions may influence price-cost markups. Lastly, we concentrate on ex-post moral hazard to introduce credit rationing. Empirical and theoretical literature suggests other channels through which financial market imperfections may influence export behavior like higher default risk, information asymmetries regarding firm attributes or imperfect financial contractibility (see Manova, 2013; Feenstra et al., 2014, among others).

## 8 Mathematical Appendix

### 8.1 Maximization problem of firm

This section derives the optimal investment and pricing behavior of a firm with export status  $l \in d, x$ , whereas  $1_{\{x_x^* > 0\}}$  takes a value of 1 if the firm is an exporter and is zero otherwise. Firms maximize expected profits (6) which can be written as follows:

$$\lambda \pi_l = \lambda X P^\sigma q_l^{\sigma-1} \left[ p_l^{1-\sigma} + 1_{\{x_x^* > 0\}} (p_x^*)^{1-\sigma} - \frac{q_l^\theta}{e_l} (p_l^{-\sigma} + 1_{\{x_x^* > 0\}} \tau (p_x^*)^{-\sigma}) \right] - \lambda k_l - f_l, \quad (53)$$

subject to the constraints (7), (8) and (10). The first order conditions for optimal domestic prices  $p_l$  and export prices  $p_x^*$ , as well as investment levels  $e_l$  and  $q_l$ , are given by:

$$(\lambda + \mu_3) X P^\sigma q_l^{\sigma-1} \left[ (1 - \sigma) p_l^{-\sigma} + \sigma p_l^{-\sigma-1} \frac{q_l^\theta}{e_l} \right] = 0, \quad (54)$$

$$(\lambda + \mu_3) X P^\sigma q_x^{\sigma-1} \left[ (1 - \sigma) (p_x^*)^{-\sigma} + \sigma \tau (p_x^*)^{-\sigma-1} \frac{q_x^\theta}{e_x} \right] = 0, \quad (55)$$

$$(\lambda + \mu_3) X P^\sigma \frac{q_l^{\theta+\sigma-1}}{e_l^2} (p_l^{-\sigma} + 1_{\{x_x^* > 0\}} \tau (p_x^*)^{-\sigma}) - \mu_1 \frac{\beta}{\varphi} e_l^{\beta-1} = 0, \quad (56)$$

$$\begin{aligned} & (\lambda + \mu_3) X P^\sigma (\sigma - 1) q_l^{\sigma-2} (p_l^{1-\sigma} + 1_{\{x_x^* > 0\}} (p_x^*)^{1-\sigma}) \\ & + (\lambda + \mu_3) X P^\sigma \frac{(\theta + \sigma - 1) q_l^{\theta+\sigma-2}}{e_l} (p_l^{-\sigma} + 1_{\{x_x^* > 0\}} \tau (p_x^*)^{-\sigma}) - \mu_1 \frac{\alpha}{K} q_l^{\alpha-1} = 0 \end{aligned} \quad (57)$$

Optimality conditions with respect to credit amount  $d_l$  and loan repayment  $k_l$  are:

$$\mu_1 - r \mu_2 = 0, \quad (58)$$

$$-\lambda + \mu_2 \lambda - \mu_3 = 0, \quad (59)$$

whereas  $\mu_1$ ,  $\mu_2$  and  $\mu_3$  are the Lagrange multipliers of the constraints (7), (8) and (10) respectively. Combining equations (58) and (59) leads to  $\frac{\lambda + \mu_3}{\mu_1} = \frac{\lambda \mu_2}{\mu_1} = \frac{\lambda}{r}$ , whereas  $\mu_3 = 0$  if incentive compatibility is not binding. The optimal prices (14) follow immediately from equations (54) and (55). Combining the optimal pricing rules with the first-order conditions for quality (56) and process innovations (57), leads to:

$$e_l = \left( \frac{\lambda \varphi A_l}{\beta r} \right)^{\frac{1}{\beta+1-\sigma}} q_l^{\frac{(\sigma-1)(1-\theta)}{\beta+1-\sigma}}, \quad (60)$$

$$q_l = \left( \frac{\lambda(1-\theta)\kappa A_l}{\alpha r} \right)^{\frac{1}{\alpha+(1-\theta)(1-\sigma)}} e_l^{\frac{\sigma-1}{\alpha+(1-\theta)(1-\sigma)}}, \quad (61)$$

where market size for domestic producers and exporters is defined as:  $A_d = XP^\sigma \left(\frac{\sigma-1}{\sigma}\right)^\sigma$ ,  $A_x = (1 + \tau^{1-\sigma})A_d$ . Equations (60) and (61) show the complementary structure of process and quality innovations, as discussed in section 3.3. Combining the two expressions leads to the optimal investment choices described by equations (11) and (12). By inserting the optimal investment levels into the first order conditions (54) and (55), one obtains the optimal price (14). Total sales of a firm with export status  $l \in d, x$  are defined by  $s_l(\varphi, \kappa) = XP^\sigma \left(\frac{q_l}{p_l}\right)^{\sigma-1} + 1_{\{x_x^* > 0\}} XP^\sigma \left(\frac{q_x}{p_x^*}\right)^{\sigma-1}$ , whereas  $p_x^* = \tau p_x$ . Inserting the optimal choices of quality innovation (12) and price setting (14) immediately leads to expression (15). The optimal loan repayment  $k_l$  follows from the constraints (7) as well as (8) and can be written as function of revenues:

$$\lambda k_l = \frac{\sigma-1}{\sigma} \lambda s_l(z) \left( \frac{1}{\beta} + \frac{1-\theta}{\alpha} \right). \quad (62)$$

## 8.2 Derivation of welfare

To derive the welfare function (49), we aggregate the price index (2) as follows:

$$P^{1-\sigma} = M_d \int \int_{(\varphi, \kappa) \in D_d} \left( \frac{q_d}{p_d} \right)^{\sigma-1} \mu_d(\varphi, \kappa) d\varphi d\kappa + (1 + \tau^{1-\sigma}) M_x \int \int_{(\varphi, \kappa) \in D_x} \left( \frac{q_x}{p_x} \right)^{\sigma-1} \mu_x(\varphi, \kappa) d\varphi d\kappa.$$

By using the expression for firm-specific quality-price ratios (22) and exploiting the labor market clearing condition (41), consumer welfare can be written as:

$$W = P^{-1} = \frac{\sigma-1}{\sigma} \beta^{-\frac{1}{\beta}} \left( \frac{1-\theta}{\alpha} \right)^{\frac{1-\theta}{\alpha}} \left( \frac{L}{r(1+v)} \right)^{\frac{\alpha+\beta(1-\theta)}{\alpha\beta}} \left[ M_d \tilde{z}_d^{\frac{\sigma-1}{\gamma}} + (1 + \tau^{1-\sigma})^{\frac{\alpha\beta}{\gamma}} M_x \tilde{z}_x^{\frac{\sigma-1}{\gamma}} \right]^{\frac{\gamma}{\alpha\beta(\sigma-1)}}.$$

Analogous to Melitz (2003), we substitute for average efficiencies  $\tilde{z}_l$  by using the relationship  $\frac{s_l(\tilde{z}_l)}{s_l(z_l)} = \left( \frac{\tilde{z}_l}{z_l} \right)^{\frac{\sigma-1}{\gamma}} = \frac{S_l}{M_l} \frac{(\sigma-1)v}{\sigma \left( \frac{1}{\lambda} + \frac{b}{\Delta\lambda} \right) f_l}$ , and exploit that  $\frac{z_x}{z_d} = \left( \frac{f_x}{f_d} \right)^{\frac{\gamma}{\sigma-1}} (1 + \tau^{1-\sigma})^{\frac{-\alpha\beta}{\sigma-1}}$ . After some modifications, this allows to write welfare per worker as a function of the cutoff efficiency  $z_d$ , as specified in equation (49).

## 8.3 Solution with Pareto distributed capabilities

To obtain an explicit solution for the cutoff efficiency  $z_d$ , we assume that firm specific capabilities  $\varphi$  and  $\kappa$  are independently Pareto distributed with positive support over  $[1, \bar{\varphi}] \times [1, \infty]$  and  $\bar{\varphi} > 1$ . The probability of drawing a particular combination of  $\varphi$  and  $\kappa$  is then given by:

$h(\varphi, \kappa) = h_\varphi(\varphi)h_\kappa(\kappa)$  with  $h_\kappa(\kappa) = \xi\kappa^{-\xi-1}$  and  $h_\varphi(\varphi) = \vartheta\frac{\varphi^{-\vartheta-1}}{1-\varphi^{-\vartheta}}$ , where  $\xi$  and  $\vartheta$  are the shape parameters of the Pareto distributions. Probabilities of success  $\chi_s$  and of belonging to the groups of non-exporters and exporters respectively  $\chi_l$ , as defined by equation (33), can be expressed as functions of cutoff efficiency levels  $z_l$ , for  $l \in d, x$ :

$$\chi_s = \frac{1}{\Psi} z_d^{\frac{-\xi}{\beta(1-\theta)}}; \chi_d = \frac{1}{\Psi} \left( z_d^{\frac{-\xi}{\beta(1-\theta)}} - z_x^{\frac{-\xi}{\beta(1-\theta)}} \right); \chi_x = \frac{1}{\Psi} z_x^{\frac{-\xi}{\beta(1-\theta)}},$$

whereby  $\Psi = \frac{\alpha\xi - \vartheta\beta(1-\theta)}{\vartheta\beta(1-\theta)} \frac{1 - \bar{\varphi}^{-\vartheta}}{\frac{\alpha\xi - \vartheta\beta(1-\theta)}{\bar{\varphi}^{\frac{\beta(1-\theta)}{\alpha\xi - \vartheta\beta(1-\theta)}} - 1}}$ . The shares of exporters and domestic sellers,  $\psi_l = \frac{\chi_l}{\chi_s}$ , are then given by:

$$\psi_x = \left( \frac{z_d}{z_x} \right)^{\frac{\xi}{\beta(1-\theta)}}; \psi_d = 1 - \left( \frac{z_d}{z_x} \right)^{\frac{\xi}{\beta(1-\theta)}},$$

with  $\frac{z_d}{z_x} = \left( \frac{f_d}{f_x} \right)^{\frac{\gamma}{\sigma-1}} (1 + \tau^{1-\sigma})^{\frac{\alpha\beta}{\sigma-1}}$ . The components of expected profits in equation (38) can be expressed as:

$$\psi_d \left( \frac{\tilde{z}_d}{z_d} \right)^{\frac{\sigma-1}{\gamma}} = \Omega \left( 1 - \left( \frac{z_d}{z_x} \right)^{\frac{\xi\gamma - \beta(1-\theta)(\sigma-1)}{\gamma\beta(1-\theta)}} \right), \quad (63)$$

$$\psi_x \left( \frac{\tilde{z}_x}{z_x} \right)^{\frac{\sigma-1}{\gamma}} = \Omega \left( \frac{z_d}{z_x} \right)^{\frac{\xi}{\beta(1-\theta)}}, \quad (64)$$

where  $\Omega = \frac{\xi\gamma}{\xi\gamma - \beta(1-\theta)(\sigma-1)}$ . The free entry condition (39) is an increasing function of the cutoff efficiency  $z_d$ :

$$E\pi = \delta f_E \Psi z_d^{\frac{\xi}{\beta(1-\theta)}}.$$

For technical reasons, we assume that the Pareto shape parameters are sufficiently large,  $\xi > \frac{\beta(1-\theta)(\sigma-1)}{\gamma}$  and  $\vartheta > \frac{\alpha\xi}{\beta(1-\theta)}$ , such that  $\Omega, \Psi > 0$ . For the further analysis, we define a measure for average efficiency  $\Delta_z$  and the average fixed costs  $\tilde{f}$  in the economy:

$$\Delta_z = 1 + \psi_x \frac{f_x}{f_d} \frac{(1 + \tau^{1-\sigma})^{\frac{\alpha\beta}{\gamma}} - 1}{(1 + \tau^{1-\sigma})^{\frac{\alpha\beta}{\gamma}}}; \tilde{f} = \psi_d f_d + \psi_x f_x.$$

Combining expected profits and the free entry condition, leads to an explicit solution for the cutoff efficiency level  $z_d$ :

$$z_d = \left( \frac{E\pi}{\delta f_E \Psi} \right)^{\frac{\beta(1-\theta)}{\xi}}, \quad (65)$$

whereas expected profits can be written as:  $E\pi = \Omega \Delta_z \Theta f_d - \tilde{f}$ .

**Number of active firms** As shown by equation (41), the number of active firms in one country is a function of labor supply  $L$  and average revenues (38). To solve for the

number of firms explicitly, we use the expressions for expected efficiencies of non-exporters and exporters (63) and (64). With Pareto distributed capabilities, average revenues can be expressed as:

$$\lambda \tilde{s} = \frac{\sigma \Omega \Delta_s \Theta f_d}{(\sigma - 1) v},$$

with  $\Delta_s = 1 + \psi_x \frac{f_x}{f_d} \frac{(1 + \tau^{1 - \sigma})^{\frac{1}{\gamma}} - 1}{(1 + \tau^{1 - \sigma})^{\frac{1}{\gamma}}}$ . The number of active firms in one country is given by:

$$M = \frac{(\sigma - 1) v L}{\sigma \Omega \Delta_s \Theta f_d \left[ 1 - \frac{\sigma - 1}{\sigma} \left( \frac{1}{\beta} + \frac{1 - \theta}{\alpha} \right) \right]}, \quad (66)$$

and the number of total varieties in one economy is defined as:  $M_x = (1 + \psi_x) M$ .

## 8.4 Proofs

**Proof of Proposition 5.** The change of the number of firms with respect to the private benefit  $b$  and the success probability  $\lambda$ , as shown in equations (47) and (48) respectively, follows immediately from the derivative of equation (66). The derivatives of the cutoff efficiency  $z_d$  (65) are given by:

$$\frac{\partial z_d}{\partial b} \frac{b}{z_d} = \frac{\beta(1 - \theta)}{\xi \Delta \lambda} \frac{\Omega \lambda b f_d \Delta_z}{E \pi} > 0, \quad (67)$$

$$\frac{\partial z_d}{\partial \lambda} \frac{\lambda}{z_d} = - \frac{\beta(1 - \theta)}{\xi \Delta \lambda^2} \frac{\Omega \lambda \lambda_b b f_d \Delta_z}{E \pi} < 0. \quad (68)$$

The general equilibrium effects of credit tightening on investment and price setting can be derived from equations (11)-(14), by taking into account incentive compatibility (17) and the changes in the cutoff efficiency (67) and (68). The responses of process and quality innovations to an increase in the private benefit  $b$  are given by:

$$\frac{\partial e_l}{\partial b} \frac{b}{e_l} = \frac{1}{\beta} \frac{b \lambda}{b \lambda + \Delta \lambda} \left( 1 - \frac{\beta(1 - \theta)(\sigma - 1)}{\xi \gamma} \frac{E \pi + \tilde{f}}{E \pi} \right), \quad (69)$$

$$\frac{\partial q_l}{\partial b} \frac{b}{e_l} = \frac{1}{\alpha} \frac{b \lambda}{b \lambda + \Delta \lambda} \left( 1 - \frac{\beta(1 - \theta)(\sigma - 1)}{\xi \gamma} \frac{E \pi + \tilde{f}}{E \pi} \right). \quad (70)$$

The investment responses are positive as long as  $\frac{\beta(1 - \theta)(\sigma - 1)}{\xi \gamma} \frac{E \pi + \tilde{f}}{E \pi} < 1$ . Note that  $\frac{\beta(1 - \theta)(\sigma - 1)}{\xi \gamma} < 1$  and  $\frac{E \pi + \tilde{f}}{E \pi} > 1$ , whereas  $\frac{\partial \left( \frac{E \pi + \tilde{f}}{E \pi} \right)}{\partial b} < 0$ . Hence, the general equilibrium response of innovations is positive whenever private benefits are sufficiently high. The derivatives of the relative

investment and the optimal price are given by:

$$\frac{\partial \left( \frac{e_l}{q_l} \right)}{\partial b} \frac{b q_l}{e_l} = \frac{\alpha - \beta}{\alpha \beta} \frac{b \lambda}{b \lambda + \Delta \lambda} \left( 1 - \frac{\beta(1 - \theta)(\sigma - 1) E \pi + \tilde{f}}{\xi \gamma E \pi} \right), \quad (71)$$

$$\frac{\partial p_l}{\partial b} \frac{b}{p_l} = \frac{\beta \theta - \alpha}{\alpha \beta} \frac{b \lambda}{b \lambda + \Delta \lambda} \left( 1 - \frac{\beta(1 - \theta)(\sigma - 1) E \pi + \tilde{f}}{\xi \gamma E \pi} \right). \quad (72)$$

The responses of investment and price setting to a change in the success probability  $\lambda$  can be derived analogously.

**Proof of Proposition 7.** The welfare reaction in equation (51) is negative if  $\frac{\gamma}{\sigma - 1} \frac{\lambda b}{\Delta \lambda + \lambda b} > \frac{\partial z_d}{\partial b} \frac{b}{z_d}$ , which leads to the following condition:

$$\frac{\partial W}{\partial b} \frac{b}{W} < 0 \text{ if } \frac{\beta(1 - \theta)(\sigma - 1) E \pi + \tilde{f}}{\xi \gamma E \pi} < 1.$$

Note that this condition is satisfied whenever the private benefit  $b$  is sufficiently high, such that the negative variety effect outweighs efficiency gains after credit tightening. Analogously, the welfare reaction in equation (50) is positive if  $\frac{\gamma \lambda b}{\Delta \lambda (\sigma - 1) \Delta \lambda + \lambda b} > -\frac{\partial z_d}{\partial \lambda} \frac{\lambda}{z_d}$ , which leads to the following condition:

$$\frac{\partial W}{\partial \lambda} \frac{\lambda}{W} > 0 \text{ if } \frac{\xi \gamma}{\beta(1 - \theta)(\sigma - 1) \lambda} \frac{E \pi}{\lambda(E \pi + \tilde{f})} > 1.$$

Thus, the welfare reaction is positive if financial frictions in terms of the private benefit  $b$  are sufficiently high. To show that the welfare loss of credit tightening is more pronounced in sectors with low investment intensity, the derivative (51) can be written as:

$$\frac{\partial W}{\partial b} \frac{b}{W} = -\frac{\lambda b}{\Delta \lambda + \lambda b} \left( \frac{\gamma}{(\sigma - 1) \alpha \beta} - \frac{(1 - \theta) E \pi + \tilde{f}}{\alpha \xi E \pi} \right).$$

Both the variety effect as well as the efficiency effect increase in investment cost parameter  $\alpha$ :  $\frac{\partial \left( \frac{\gamma}{(\sigma - 1) \alpha \beta} \right)}{\partial \alpha} = \frac{(1 - \theta)}{\alpha^2} > 0$ , and  $\frac{\partial \left( \frac{E \pi + \tilde{f}}{E \pi} \right)}{\partial \alpha} > 0$ . Hence, we consider the limit case if  $\alpha$  approaches infinity. Note that  $\lim_{\alpha \rightarrow \infty} \tilde{f} = f_d$  and  $\lim_{\alpha \rightarrow \infty} E \pi = f_d (\Theta - 1) > 0$ . In the limit case, the variety effect converges to:  $\lim_{\alpha \rightarrow \infty} \frac{\gamma}{\alpha \beta} = \frac{\beta + 1 - \sigma}{\beta} > 0$ ; whereas the efficiency effect disappears:  $\lim_{\alpha \rightarrow \infty} \frac{(1 - \theta) E \pi + \tilde{f}}{\alpha \xi E \pi} = 0$ . Thus, welfare losses become larger in sectors with low quality differentiation due to the dominating variety effect. A similar argument holds for the investment

cost parameter  $\beta$  as:  $\frac{\partial(\frac{\gamma}{(\sigma-1)\alpha\beta})}{\partial\beta} = \frac{1}{\beta^2} > 0$  and  $\frac{\partial(\frac{E\pi+\tilde{f}}{E\pi})}{\partial\beta} > 0$ . In the limit case, for the variety effect it holds that:  $\lim_{\beta \rightarrow \infty} \frac{\gamma}{\alpha\beta} = \frac{\alpha+(1-\sigma)(1-\theta)}{\alpha} > 0$ . Note, however, that the efficiency effect does not disappear, but converges to a positive limit:  $\lim_{\beta \rightarrow \infty} \frac{(1-\theta)E\pi+\tilde{f}}{\alpha\xi} > 0$ .

## 8.5 Extension: external financing of fixed costs

If fixed costs have to be financed by external capital, the budget constraint (7) changes to:  $d_l \geq f_l + \frac{1}{\kappa}q_l^\alpha + \frac{1}{\varphi}e_l^\beta$ , and the agency cost parameter can be written as:  $\Theta = r + \frac{\lambda b}{\lambda - \lambda_b}$  (compare section 3.4). In that case, an increase in the borrowing rate leads to an additional effect along the extensive margin without changing the direction of firm responses in general equilibrium. In contrast to shocks related to financial frictions, there is still a negative response of process and quality innovations to an increase in the borrowing rate:

$$\frac{\partial e_l}{\partial r} \frac{r}{e_l} = -\frac{1}{\beta} \left( \frac{b\lambda}{b\lambda + r\Delta\lambda} + \frac{\sigma - 1}{\gamma} \frac{\partial z_d}{\partial r} \frac{r}{z_d} \right) < 0, \quad \frac{\partial q_l}{\partial r} \frac{r}{e_l} = -\frac{1}{\alpha} \left( \frac{b\lambda}{b\lambda + r\Delta\lambda} + \frac{\sigma - 1}{\gamma} \frac{\partial z_d}{\partial r} \frac{r}{z_d} \right) < 0,$$

whereas the efficiency effect is given by:

$$\frac{\partial z_d}{\partial r} \frac{r}{z_d} = \frac{\beta(1-\theta)}{\xi} \frac{\Omega r f_d \Delta_z - r \tilde{f}}{E\pi} > 0,$$

and expected average profits are defined as:  $E\pi = \Omega \left( r + \frac{b\lambda}{\Delta\lambda} \right) f_d \Delta_z - r \tilde{f}$ .

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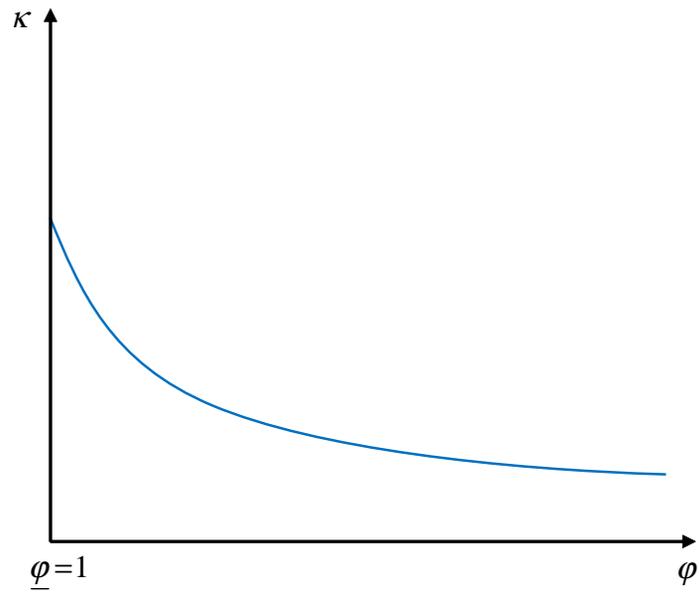


Figure 1: Iso-efficiency curve in two-dimensional capability space

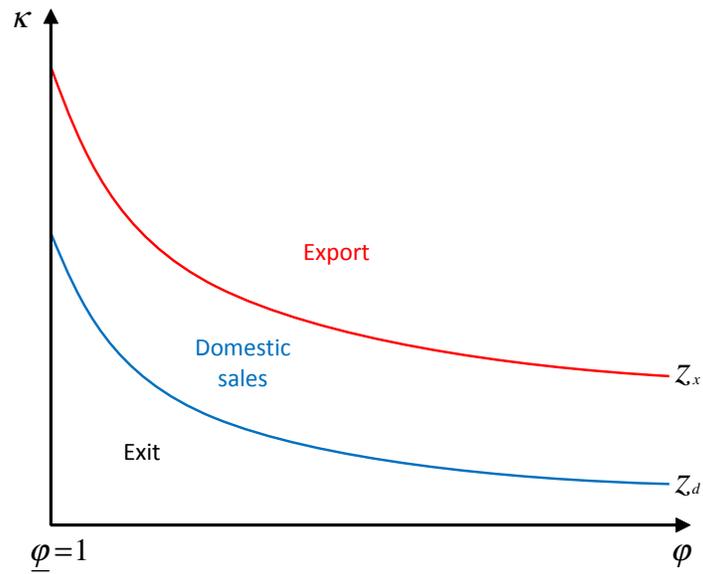


Figure 2: Selection pattern in open economy

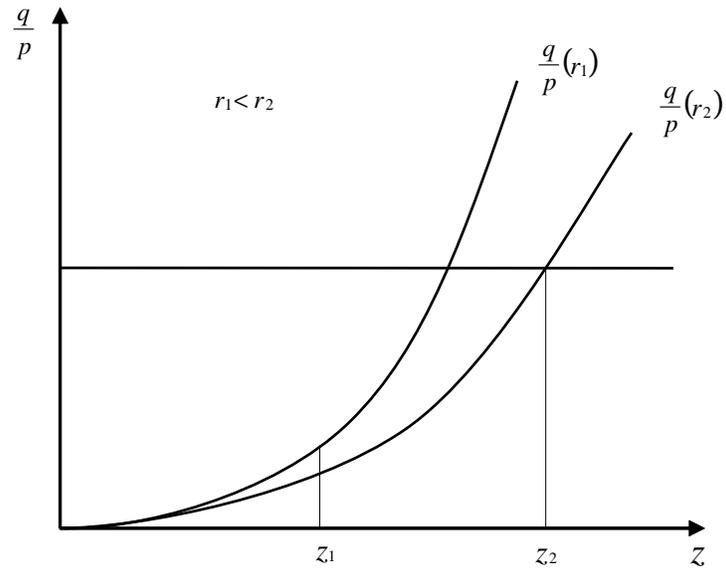


Figure 3: Financial frictions and quality sorting

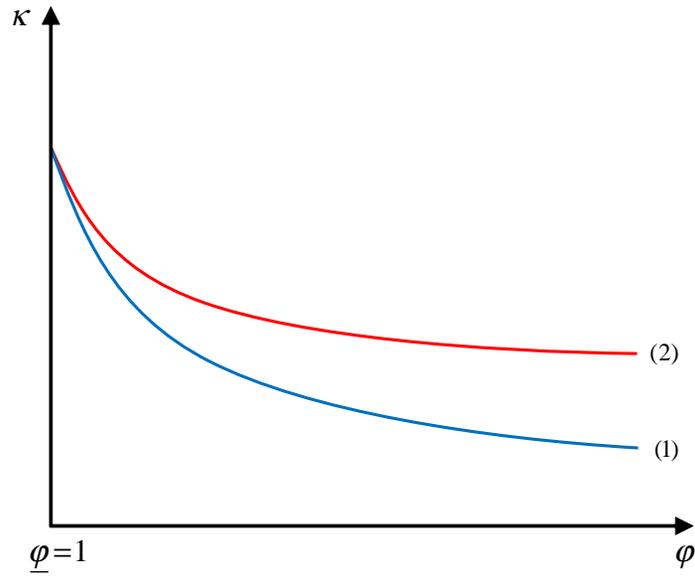


Figure 4: Iso-efficiency curve for low (1) and high (2) vertical product differentiation

Parameter	Description	Value
$\sigma$	Elasticity of substitution	2
$\alpha, \beta$	Investment cost parameter	2
$\theta$	Marginal cost parameter	0.5
$\xi, \vartheta$	Pareto shape parameters	3 / 6
$\tau$	Iceberg-transportation costs	1.9
$f_x$	Fixed trade costs	7
$f_d$	Fixed production costs	1
$\lambda$	Success probability diligent behavior	0.7
$\lambda_b$	Success probability shirking	0
$b$	Private benefit	5 / 10

Table 2: Parameter values

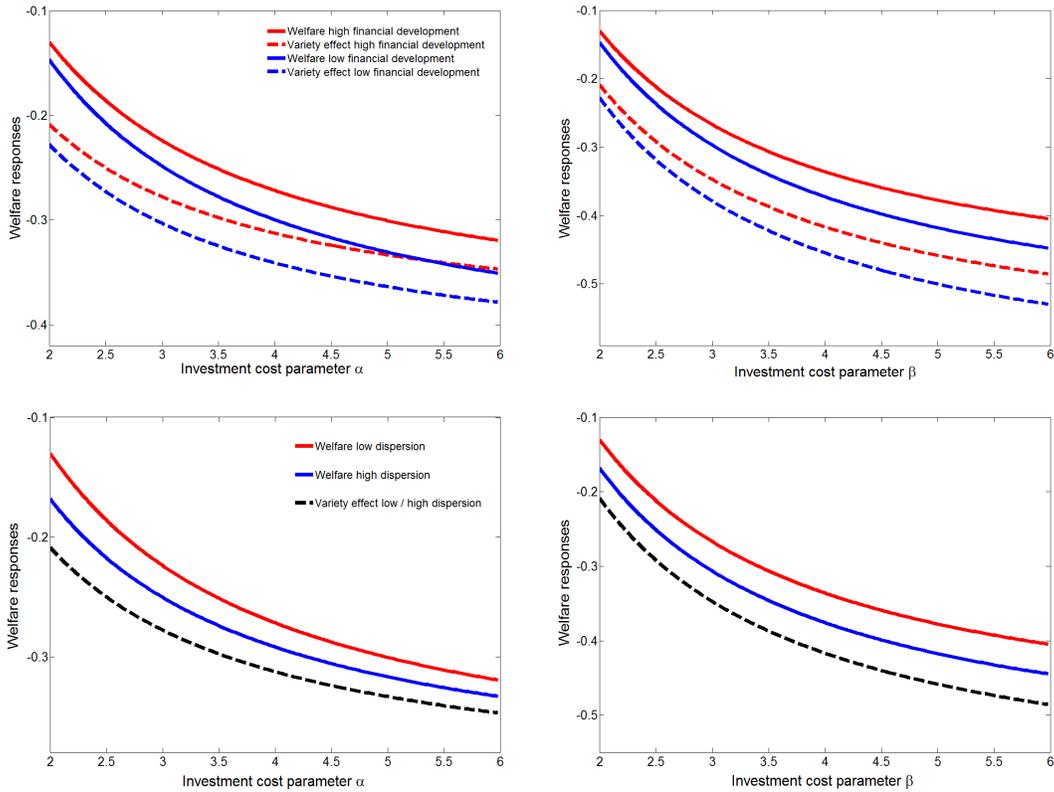


Figure 5: Welfare responses to credit tightening for different degrees of investment intensity