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

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Abstract

This paper analyzes the effects of credit frictions on prices, productivity and welfare in a trade model with two types of firm heterogeneity. Producers differ in their capabilities to conduct process and quality innovations, and require external finance to invest in innovations. Stronger credit frictions lead to firm exit, higher innovation activity of surviving producers, and ambiguous effects on prices, depending on a key variable, the degree of quality differentiation in a sector. Accounting for cost-based and quality-based sorting of firms in a unified framework allows us to show that the reactions of prices and of commonly used productivity measures do not necessarily reflect welfare implications. Credit frictions lead to distortions through aggravated access to finance and endogenous price adjustments, such that the responses of quantity-based and revenue-based productivity differ substantially. In a counterfactual analysis, we show that these differential effects are quantitatively important.

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1 Introduction

External credit plays a crucial role to finance production and innovation decisions. In the presence of credit constraints, firms face access barriers to external credit and higher borrowing costs (Berman and Héricourt, 2010; Beck, 2013). This has negative effects on innovation activity and market participation, especially for smaller firms. The exposure to credit frictions is also highly relevant in international trade as exporting usually requires additional upfront costs for investments in marketing, product customization or distribution networks.[1] It is important to understand how financial development influences firm's innovation choices as it does not only affect market participation, but also productivity and consumer prices of goods traded. These price and productivity responses to credit constraints are perceived as important determinants of welfare and are receiving increasing attention in the literature.

In this paper, we consider two types of endogenous innovations and analyze the implications of credit frictions for prices, productivity, and welfare. The first type is process innovations that increase a firm's productivity, such as improvements in technological know-how or production methods. As a second type, quality innovations allow firms to offer products of better quality at higher prices. Existing studies typically focus on only one of the two dimensions how credit frictions affect innovation choices, treating either productivity or quality as exogenous. We show that taking into account both channels is important to understand the implications of credit frictions for prices, productivity measures and welfare.

We develop a general equilibrium model of international trade with credit constraints, where producers differ in their capabilities to conduct process and quality innovations. Investments are associated with fixed outlays that decrease in firm-specific capabilities and innovation choices endogenously determine marginal production costs. Depending on their capabilities, firms choose different investment levels and prices. Process innovations are improvements in technological know-how or production methods which decrease marginal costs and hence increase the cost-based productivity of a firm for any given quality level. Quality innovations shift demand up but also increase marginal production costs due to additional marketing or advertising expenditures. We assume that firms have to raise external finance for fixed investment outlays and face credit frictions based on moral hazard similar to Holmstrom and Tirole (1997). 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 credit and exit the market.[2]

[1]See Aghion et al. (2007), Beck et al. (2008) for evidence on firm size and credit frictions; Paunov (2012) and Archibugi et al. (2013) show evidence for financial shocks on innovation. Foley and Manova (2015) provide a review of the trade and finance literature.

[2]Other models that introduce imperfect capital markets based on moral hazard are Antràs and Caballero

We analyze the implications of higher credit costs and aggravated access to finance through the lens of the model. We first highlight that our analysis contributes to a better understanding of the relation between credit frictions and prices depending on the nature of the financial shock. In particular, the effects of credit constraints depend on the scope for vertical product differentiation, which is defined as the ratio of outlays for quality innovations to outlays for process innovations. This measure is determined by technological parameters of the investment cost functions, and is closely related to sectoral proxies of quality differentiation, such as the ratio of R&D to sales (see Kugler & Verhoogen, 2012). An increase in credit costs negatively affects both types of innovation and triggers opposing quality and cost effects on marginal production costs and prices. If the scope for vertical product differentiation is high, the quality adjustment effect dominates and higher credit costs lead to lower firm-level prices. In these sectors, prices and firm size are positively correlated. In contrast, stronger credit frictions aggravate access to external finance, which reduces competition through the exit of firms and hence increases incentives to innovate. If the scope for vertical product differentiation is high, remaining firms react to this shock by shifting resources relatively more towards quality innovations, which results in higher prices. In this case, a positive effect of credit constraints on prices, as well as a positive relation between firm size and prices can occur simultaneously.

Our unified framework further shows that the relation between credit frictions, prices and welfare is more nuanced than suggested by models that consider only one dimension of adjustment, either quality-based or cost-based sorting.[3] We highlight that inferring welfare implications from price effects will lead to inaccurate conclusions if general equilibrium adjustments of innovations are not taken into account. This has also been pointed out previously in Fan et al. (2015) and Fan et al. (2020), where the latter discuss the problem that this ambiguity poses for measuring mark-ups or trade costs using price data. We show that this ambiguity can be dissolved by controlling for the scope for vertical product differentiation. This is an observable characteristic that can help to overcome the quality puzzle when using price data and avoid potential misspecification in micro-econometric models.

Our results show that whether welfare and price effects are positively or negatively correlated depends on the scope for vertical product differentiation as well. Hence, we relate to recent studies that infer welfare implications from firm-level responses of prices and markups in the context of trade shocks (Behrens et al., 2014; Blaum et al., 2018; Fan et al., 2020). We contribute to this literature by showing that credit frictions distort the relationship between firm-level prices and welfare through the extensive margin.[4]

(2009), von Ehrlich and Seidel (2015), Egger and Keuschnigg (2015), as well as Irlacher and Unger (2018).

[3]Welfare effects across sectors can be interpreted as changes in sectoral quality-adjusted price indexes.

[4]By considering firm heterogeneity in foreign input sourcing, Blaum et al. (2018) analyze gains from

Accounting for endogenous innovations has also important implications for the interpretation of empirical studies that consider productivity effects and typically focus on revenue-based measures (e.g. Forlani et al., 2016; Garcia-Marin and Voigtländer, 2019). In our framework, aggravated access to finance leads to exit of firms and hence increases sales of remaining producers due to lower competition, which raises average productivity, measured either revenue-based (TFPR) or quantity-based (TFPQ). Stronger credit frictions induce adjustments of innovations and prices leading to differential responses of these productivity measures that can even move in opposite directions. If the scope for vertical product differentiation is large, positive price effects lower the reaction of TFPQ compared to TFPR.

These differential responses highlight that quantifying the implications of credit frictions is crucial to evaluate the role of endogenous innovations in our framework. Hence, we calibrate our model to match sectoral characteristics related to innovation, exporting, and financial development for Columbia in 2016. We quantify the effects of stronger credit constraints, and compare them to the ones of three counterfactual scenarios that capture existing classes of models in the literature. These are nested as special cases in our framework and include models (i) without endogenous innovations, with (ii) only process innovations, and (iii) only quality innovations. In all four variants, a credit shock that aggravates access to external finance leads to increases in average TFPR due to exit of firms. However, the underlying reactions of prices and average TFPQ differ substantially.

In the first scenario without endogenous innovations, credit frictions lead to negative reactions of average prices across all sectors due to exit of least productive firms that charge higher prices. In the second case, remaining producers additionally increase process innovation in response to the credit shock. In both cases, negative price effects attenuate the responses of TFPR compared to TFPQ by over 50%. In contrast, the third counterfactual scenario with quality adjustments implies a positive reaction of average prices, which drives up the response of TFPR relative to TFPQ. In 9 out of 21 sectors with high quality differentiation, the TFPQ response even turns negative. Compared to these benchmark cases, the simulation of our model with two types of innovations shows that the direction and magnitude of price reactions differ substantially depending on the scope for vertical product differentiation across sectors. Only in the model variant without innovations, there is a strong positive correlation between the reaction of prices and welfare to credit frictions. We further highlight that accounting for endogenous adjustments of innovations increases

input trade and effects on firm-level prices. Fan et al. (2020) stress that accounting for endogenous quality heterogeneity is crucial for the responses of welfare and prices with respect to tariff shocks. Behrens et al. (2014) show that trade integration leads to changes of firm-level markups ambiguous to welfare responses. Our model features constant markups, whereas Altomonte et al. (2021) show that firm-level heterogeneity in credit frictions explains part of the dispersion of prices and markups.

the magnitude of welfare losses from credit constraints by 45% compared to the benchmark model without endogenous innovations.

Related literature. Based on these counterfactual scenarios, our analysis highlights that accounting for the interaction between endogenous innovations and credit frictions is quantitatively important compared to three strands in the literature. The first class of models features cost-based sorting of heterogeneous firms as in Melitz (2003) without endogenous innovations. Hsieh and Klenow (2009) use such a framework to identify resource misallocation across firms by analyzing the difference between revenue-based and quantity-based productivity measures. While the authors do not consider selection effects of firms, allowing for fixed costs implies that financial development influences TFP through adjustments on the extensive margin (Buera et al., 2011; Midrigan and Xu, 2014). The literature on trade and finance highlights negative effects of credit constraints on firm-level exports and the probability of exporting (Berman and Héricourt, 2010; Minetti and Zhu, 2011; Muûls, 2015). If firms have to finance fixed export costs (Manova, 2013; Chaney, 2016), credit frictions do not affect prices directly but aggravate the selection of lower productivity firms into foreign markets, and thus change average marginal costs, as well as average prices, of participating firms. If external financing is related to variable export costs, there is a positive relation of credit constraints and prices (Manova, 2013; Feenstra et al., 2014). These models predict a negative correlation between firm size and prices (Roberts and Supina, 1996; Foster et al., 2008), and do not capture that innovation choices react endogenously to financial shocks.[5]

A second strand of literature highlights a positive relation of prices with firm size pointing to the important role of vertical product differentiation (Baldwin and Harrigan, 2011; Johnson, 2012; Kugler and Verhoogen, 2012; Crozet et al., 2012; Manova and Zhang, 2012).[6] Our modeling approach builds on extensions of international trade models by quality sorting (Baldwin and Harrigan, 2011; Johnson, 2012) as well as endogenous quality and input choices (Kugler and Verhoogen, 2012; Antoniades, 2015). In this context, existing studies show that credit frictions reduce product quality leading to lower marginal production costs and prices (Fan et al., 2015; Bernini et al., 2015; Crinò and Ogliari, 2017; Ciani and Bartoli, 2020). We contribute to this strand in the literature by showing that accounting for the nature of the credit shock and the differential responses of quality and process innovations is crucial to understand the relation between price reactions and welfare implications.

[5] In contrast, Secchi et al. (2016) document a positive correlation between prices and credit constraints, as well as a positive relation between prices and firm size. The first relation points to cost-based sorting, which, however, would suggest a negative relation between firm size and prices. This result is rationalized in a model with endogenous markups and switching costs for consumers between differentiated varieties.

[6] Whereas we focus on single product firms, Eckel et al. (2015) study the determinants of cost-based and quality-based competences in the context of multi-product firms.

With respect to the third counterfactual scenario, our analysis is related to a class of models that features productivity-enhancing investment and one type of firm heterogeneity (Bustos, 2011; Lileeva and Trefler, 2010; Yeaple, 2005). These models typically consider a discrete innovation choice and focus on selection effects across firms, while our framework allows for endogenous adjustments of innovations. Related, Impullitti and Licandro (2018) consider dynamic effects of innovations and show that endogenous productivity growth increases gains from trade through selection of firms. The dynamic effects of credit frictions have received attention to explain financing patterns (De Fiore and Uhlig, 2011; Crouzet, 2018), innovation and productivity development (Midrigan and Xu, 2014), as well as adjustments of new exporters compared to international trade models with sunk export entry costs (Kohn et al., 2016). Consistent with a dynamic multi-industry model of trade, Leibovici (2021) shows that financial development leads to reallocation of international trade shares from labor- to capital-intensive industries. Brooks and Dovis (2020) highlight that accounting for endogenous debt limits is important to evaluate the role of credit frictions for the gains from trade in dynamic settings. We abstract from firm dynamics, but rather highlight the differential implications of financial shocks when both process and quality innovations are taken into account. One advantage of our model is that it considers extensive margin effects, adjustments of endogenous innovations, as well as selection into exporting, while remaining highly tractable by offering closed-form solutions.

While we focus on the implications of credit frictions in the presence of innovations, Berthou et al. (2020) show that the effects of trade on welfare and productivity are not monotonic when misallocation across firms is taken into account. The model's implications are also related to studies that estimate the importance of both cost-based and quality-based determinants for firm-level success in export markets without considering credit frictions (Hottman et al., 2016; Aw and Lee, 2017; Roberts et al., 2017; Garcia-Marin and Voigtländer, 2019). Consistent with cost-based sorting in our framework, Garcia-Marin and Voigtländer (2019) identify a downward bias of TFPR, as more efficient firms set lower prices, and show that the use of TFPQ allows to measure export-related efficiency gains. Forlani et al. (2016) show that heterogeneity in markups and demand shocks is as important as differences in productivity to explain firm size, while demand factors are an important determinant of export status and TFPR. These studies typically do not take into account the impact of credit frictions on innovation choices that influence cost and quality components of firm performance. While we focus on symmetric countries, Antràs and Caballero (2009) show in a two-factor, two-sector model that trade and capital mobility are complements in less financially developed economies.

The next section sets up the model, and Section 3 presents the general equilibrium. We analyze the effects of credit frictions on prices, productivity measures, and welfare in Section 4. Section 5 quantifies the effects of credit frictions compared to three benchmark cases to highlight the role of endogenous innovations. Finally, Section 6 concludes.

2 Setup of the model

We consider a trade model with two identical countries, populated by L consumers. Each individual offers one unit of labor and owns one unit of capital, where the nominal wage is chosen as numéraire ($w = 1$).

2.1 Consumers and technology

Preferences of a representative consumer in one country are characterized by a CES utility function over a continuum of differentiated varieties, $X = \left[\int_{i\in\Omega} (q_i x_i)^{\frac{\sigma-1}{\sigma}} di\right]^{\frac{\sigma}{\sigma-1}}$, where $i \in \Omega$ denotes the variety, $\sigma > 1$ is the elasticity of substitution, and q_i stands for the quality of a product.[7] The demand for one differentiated variety i increases in the quality level and decreases in the price, $x_i = q_i^{\sigma-1} X \left(\frac{p_i}{P}\right)^{-\sigma}$, where the quality-adjusted price index is defined as $P = \left[\int_{i\in\Omega} \left(\frac{p_i}{q_i}\right)^{1-\sigma} di\right]^{\frac{1}{1-\sigma}}$. 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 differentiated sector of the economy is characterized by monopolistic competition. Each active firm manufactures one differentiated variety i and faces three different types of costs: (i) outlays for process innovations and quality innovations, (ii) marginal production costs that are affected by the choices of innovation, and (iii) fixed costs of production. For notational simplicity, we neglect the index i for firm-variables throughout the paper, but rather denote the export status of a firm by $j \in \{h, l\}$, where $j = h$ stands for non-exporters, and $j = l$ denotes exporters. The novel element in our setting is that firms decide on the optimal levels of both process innovations e_j and quality innovations q_j. These investments are associated with fixed outlays defined as follows:

$$C_q(\kappa, q_j) = \frac{q_j^{\alpha}}{\kappa};\ C_e(\varphi, e_j) = \frac{e_j^{\beta}}{\varphi}, \tag{1}$$

where C_q can be interpreted as investment costs for product design and development, and C_e reflects costs for technology improvements. The parameters α and β are exogenously

[7]By introducing a quality component in the utility function, we follow the quality and trade literature, see e.g. Baldwin and Harrigan (2011), Kugler and Verhoogen (2012), and Hallak and Sivadasan (2013).

given and determine the convexity of the investment cost function Producers differ in their capabilities to invest in process innovations φ and quality upgrades κ. Higher values of the firm-specific draws scale down investment costs and hence increase incentives to innovate. We refer to κ as the quality-based capability of a firm, which could for example reflect the effectiveness to generate and implement innovative ideas for quality upgrades, or to meet consumer tastes to a large extent (Hallak and Sivadasan, 2013). We denote φ as the cost-based capability of the firm. This capability captures how effective the firm can implement innovations that reduce production costs. Note that the cost functions in Equation (1) can be interpreted as production functions for quality and processes, where $\frac{1}{\alpha}$ and $\frac{1}{\beta}$ reflect the elasticities of quality and processes to innovation outlays.[8] Low values of α and β imply that one additional unit of investment spending is very effective.

As a second component, we consider marginal production costs mc. In heterogeneous-firms models à la Melitz (2003), these costs are typically given by the inverse of the exogenous productivity draw. However, in our model the two innovation choices affect marginal production costs mc in opposite directions:

$$mc(e_j, q_j) = \frac{q_j^{\theta}}{e_j} \text{ , with } 0 < \theta < 1. \tag{2}$$

The benefit of process innovations e_j is a reduction of marginal production costs. Quality innovations q_j increase demand for one variety (compare section 2.1), but are associated with higher labor requirements. The exogenous technology parameter θ 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 the use of higher quality inputs.[9] This common assumption in the quality and trade literature has been crucial to explain the positive correlation between export unit values and distance (Baldwin and Harrigan, 2011), as well as the positive relation between export prices and firm size (Kugler and Verhoogen, 2012; Manova and Zhang, 2012). Marginal production costs are larger for exporters ($j = l$) due to iceberg-type transportation costs, such that $\tau > 1$ units of a good have to be shipped for 1 unit to arrive. As a third component, we assume that exporters face higher fixed costs of production than non-exporters, such that $f_l > f_h$.

As we allow for both cost-based and quality-based sorting with fixed outlays, our model is closely related to Sutton (2007, 2012) and Hallak and Sivadasan (2013). Compared to

[8]The production functions for quality and processes can be written as $q_j = (\kappa C_q)^{\frac{1}{\alpha}}$, and $e_j = (\varphi C_e)^{\frac{1}{\beta}}$. A similar production function for quality only is assumed by Kugler and Verhoogen (2012).

[9]The quality and trade literature endogenizes the quality choice of firms by assuming a positive relation between output quality and marginal costs, which is often modeled by an input choice, for instance, Kugler and Verhoogen (2012) and Johnson (2012).

previous work, we analyze the impact of credit conditions on two types of investments and price setting both in partial and general equilibrium. Motivated by a time lag between investment outlays and the realization of sales, we assume that firms have to rely on external credit to cover fixed costs and expenditures associated with endogenous innovations (1).

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 φ and κ from a joint probability distribution $g(\varphi, \kappa)$.[10]

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.

Note that we abstract from dynamic effects of innovation, which play an important role as innovation and financing choices shape the performance of firms over time.[11] We first describe the financial contracting and profit maximization of firms conditional on access to finance. In Section 2.3, we show how moral hazard influences the selection of firms into production and exporting. After entry, active producers decide whether to sell their product to an identical foreign country. Depending on their export status $j \in h, l$, firms choose the optimal levels of process (e_j) and quality innovations (q_j).

We assume that labor is used for variable production costs, while firms have to borrow external capital to finance fixed costs and endogenous innovation outlays at the beginning of the production period. After these investments, production and hence profits realize with success probability $\lambda < 1$ at the end of the period. If the project fails, the bad shock prevents firms from production, which implies that they realize no sales, do not spend variable production costs, and hence cannot repay the loan to the lender. A firm's demand

[10] To obtain closed-form solutions, we assume a Pareto distribution in Section 3.

[11] In a dynamic model of heterogeneous firms and innovation, Impullitti and Licandro (2018) show that endogenous productivity growth increases gains from trade through selection of firms. Allowing for dynamics in a heterogeneous firms model, Crouzet (2018) study the choice between bank and bond finance, where a credit shock exposes firms to higher risk of financial distress.

for external credit d_j is given by the following constraint:

$$d_j \geq f_j + \frac{q_j^{\alpha}}{\kappa} + \frac{e_j^{\beta}}{\varphi}. \tag{3}$$

As we are mainly interested in the impact of credit frictions on investments and price setting, we abstract from external financing of fixed entry costs f_e. In general equilibrium, this implies that average profits are used to cover fixed costs of potential entrants.[12] The credit repayment k_j has to be sufficiently high to ensure that external investors do not incur losses from lending:

$$\lambda k_j \geq r d_j, \tag{4}$$

where $r > 1$ captures the gross borrowing rate which we treat as fixed. This assumption is primarily taken for exposition reasons in order to highlight the main implications of the framework most clearly. One can think of the borrowing rate being fixed because of completely elastic capital supply in the economy, or because of an outside sector that produces a homogenous good under perfect competition and constant returns to scale with capital as the only input. While we provide results with a fixed interest rate in the main text, we show in Section 4 that the key implications of our model remain valid if endogenous adjustments of the interest rate are taken into account. We further assume perfect competition in the financial sector such that both the budget constraint (3) and the investor's participation constraint (4) hold with equality.

We assume that the probability of success depends on a project choice of the firm which is non-verifiable for external investors and thus prone to moral hazard (Holmstrom and Tirole, 1997). 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 λ. On the other hand, if the agent chooses to misbehave, the probability of success is zero, but the borrower can reap a private benefit $bf_j > 0$, which we denote in terms of fixed production costs.

We follow Holmstrom and Tirole (1997) and interpret the private benefit as opportunity costs from managing the project diligently. The agent faces incentives to implement the project in a more pleasant way or to pursue own advantages at the expense of investment success. This managerial benefit of shirking might be reduced by improved investor protection or stronger enforceability of financial contracts, and hence is inversely related to a country's financial development (Antràs et al., 2009). Intuitively, private benefits in case of shirking are proportional to fixed production costs which are part of the total credit amount. This assumption enhances tractability of our model as it allows us to express the effect of

[12] See the discussion in Section 3. In the Online Appendix, we show that the main results of our model remain valid if we assume that fixed entry costs have to be financed by external credit as well.

credit frictions relative to other determinants of export success, such as trade costs. All our results remain qualitatively valid if we assume that the private benefit is a constant. In the Online Appendix, we also show that the key insights of our model hold if the private benefit is related to the total credit amount.[13] Note that realized profits and loan repayments are zero in case of shirking.[14] Hence, to rule out losses from lending, the optimal credit contract has to satisfy the following incentive compatibility constraint:

$$\lambda \pi_j \geq b f_j. \tag{5}$$

2.2 Optimal firm behavior

We first discuss optimal behavior of firms that have access to external finance, and turn to the role of the incentive compatibility constraint for the selection of firms into production and exporting in the following subsection. Depending on their export status $j \in h, l$, firms choose optimal investment levels and prices to maximize expected profits subject to the constraints (3) and (4):

$$\max_{p_j, p_l^*, e_j, q_j} \lambda \pi_j = \lambda \left[p_j x_j + 1_{\{j=l\}} p_l^* x_l^* - mc(q_j, e_j) \left(x_j + 1_{\{j=l\}} \tau x_l^* \right) - k_j \right], \tag{6}$$

where demand is described in section 2.1, and the dummy variable $1_{\{j=l\}}$ takes a value of 1 if the firm exports and is zero otherwise. We denote p_j as the domestic price of a (non-) exporter and p_l^* as the export price. Note that marginal costs (2) and hence also domestic prices differ across non-exporters and exporters as they have different incentives to innovate. Optimal choices of process and quality innovations are given by:[15]

$$e_j(\varphi, \kappa) = \Psi_1 \left(A_j / r \right)^{\frac{\alpha}{\gamma}} \kappa^{\frac{(\sigma-1)(1-\theta)}{\gamma}} \varphi^{\frac{\alpha + (1-\theta)(1-\sigma)}{\gamma}}, \tag{7}$$

$$q_j(\varphi, \kappa) = \Psi_2 \left(A_j / r \right)^{\frac{\beta}{\gamma}} \kappa^{\frac{\beta+1-\sigma}{\gamma}} \varphi^{\frac{\sigma-1}{\gamma}}, \tag{8}$$

whereby $\gamma \equiv \alpha\beta + (1-\sigma)\left[\alpha + (1-\theta)\beta\right]$, and $\Psi_1 \equiv \lambda^{\frac{\alpha}{\gamma}} \left(\frac{1-\theta}{\alpha}\right)^{\frac{(\sigma-1)(1-\theta)}{\gamma}} \beta^{-\frac{\alpha+(1-\theta)(1-\sigma)}{\gamma}}$, $\Psi_2 \equiv \lambda^{\frac{\beta}{\gamma}} \left(\frac{1-\theta}{\alpha}\right)^{\frac{\beta+1-\sigma}{\gamma}} \beta^{\frac{1-\sigma}{\gamma}}$. The terms $A_h \equiv XP^{\sigma}\left(\frac{\sigma-1}{\sigma}\right)^{\sigma}$, $A_l \equiv (1+\tau^{1-\sigma})A_h$ capture market characteristics for non-exporters and exporters respectively. Consistent with theoretical and empirical work on investment activity in international trade, our model suggests a positive

[13] This extension is related to the variable investment model of Holmstrom and Tirole (1997), whereas our benchmark model resembles the fixed investment variant.

[14] Holmstrom and Tirole (1997) assume a positive but smaller probability of success in case of shirking. For notational simplicity, we set this probability to zero without loss of generality.

[15] See the Online Appendix for a detailed derivation.

relationship between innovation and market size.[16] As exporters spread investment costs across both markets, they face larger incentives to engage in quality and process innovations, $(A_l > A_h)$, whereas iceberg transportation costs τ and the borrowing rate r reduce investment activity. Note that the market variables A_j cannot be affected by a single firm, but will be endogenously determined in the general equilibrium analysis of Section 3.

In order to ensure an interior solution for both types of innovation choices, we assume that the combination of investment cost parameters is sufficiently large, such that $\gamma > 0$. Intuitively, this condition imposes a maximum limit on the extent to which quality and process innovations increase the sales of a firm.[17] If we further assume that investment costs are sufficiently convex, such that $\alpha, \beta > (\sigma - 1)(2 - \theta)$, then quality and process innovations are complements that increase in both capabilities φ and κ. Note that this condition is a sufficient, but not necessary condition for $\gamma > 0$. Consequently, producers will always invest in both types of innovation.

The success of a producer in the market results from the ability to invest in both processes and product quality at low costs. Hence, we define the "combined capability" of a firm as a measure that summarizes information about both capability draws:[18]

$$z = \varphi^{\alpha} \kappa^{\beta(1-\theta)} \tag{9}$$

This combined capability determines a firm's effective marginal cost which immediately follows from Equations (8) and (11):

$$c_j^e(z) \equiv \frac{q_j^{\theta}}{e_j} \frac{1}{q_j}(z) = \Psi_3 (r/A_j)^{\frac{\alpha+\beta(1-\theta)}{\gamma}} z^{-\frac{1}{\gamma}}, \tag{10}$$

where $\Psi_3 \equiv \lambda^{-\frac{\alpha+\beta(1-\theta)}{\gamma}} \left(\frac{\alpha}{1-\theta}\right)^{\frac{\beta(1-\theta)}{\gamma}} \beta^{\frac{\alpha}{\gamma}}$. As usual in models with monopolistic competition and CES demand, firms set the optimal price as a constant markup over marginal production costs. However, the latter are endogenously determined by the two innovation choices, where p_j denotes the domestic price of a firm with export status $j \in h, l$:

$$p_j(\varphi, \kappa) = \frac{\sigma}{\sigma - 1} c_j^e(z) q_j(\varphi, \kappa), \tag{11}$$

and $p_l^*(\varphi, \kappa) = \tau p_l(\varphi, \kappa)$ stands for the foreign price of exporters. The pricing rule cap-

[16]See Bustos (2011) as well as Kugler and Verhoogen (2012), among others.

[17]Kugler and Verhoogen (2012) impose a similar condition for the case of endogenous quality innovations.

[18]Similar to our setting, Hallak and Sivadasan (2013) summarize a firm's cost-based capability and quality-based capability in one measure denoted by "combined productivity". As we analyze effects of credit frictions on firm productivity measures in Section 4, we do not follow this denotation.

tures two opposing effects of investment behavior. A higher level of process innovations enhances production efficiency, whereas quality innovations increase marginal costs according to Equation (2). Consequently, the optimal price decreases in the cost-based capability φ, but increases in the quality-based capability κ.[19] 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).

Lower effective marginal production costs increase demand and hence total sales of a firm with export status j:

$$s_j(z) = p_j(\varphi,\kappa)\, x_j(\varphi,\kappa) + 1_{\{x_l^*>0\}} p_l^*(\varphi,\kappa)\, x_l^*(\varphi,\kappa) = A_j \frac{\sigma}{\sigma-1}\left(c_j^e(z)\right)^{1-\sigma}, \tag{12}$$

where x_j denotes the domestic quantity and the exported quantity is given by $x_l^* = \tau^{-\sigma} x_l$. We express total firm profits as a function of expected sales:

$$\lambda\pi_j(z) = \frac{\gamma}{\alpha\beta\sigma}\lambda s_j(z) - r f_j, \tag{13}$$

where $\gamma/(\alpha\beta\sigma)$ captures the fraction of sales that is left after paying variable production costs and outlays for both process and quality innovations. Without endogenous innovations, this share simplifies to $1/\sigma$ as in Melitz (2003). From Equations (10) - (13), it follows that firms with the same z charge the same quality-adjusted price, and earn the same revenues as well as profits, but will differ in their investment levels and prices. If one firm has a low cost-based capability φ, but a large quality-based capability κ, it will invest relatively more in quality compared to process innovations, which leads to higher marginal production costs and prices. Conversely, a firm with the same "combined capability", but relatively lower κ compared to φ, will invest more in process innovations and hence set a lower price.

Our model features an important distinction between investment levels and outlays for investment. The levels of process and quality innovations depend on the two capability draws. However, outlays for innovations are a constant fraction of firm sales and hence are determined by the "combined capability" of a firm:[20].

$$\frac{1}{\varphi}e_j^{\beta}(z) = \frac{\sigma-1}{\beta\sigma r}\lambda s_j(z);\ \ \frac{1}{\kappa}q_j^{\alpha}(z) = \frac{(\sigma-1)(1-\theta)}{\alpha\sigma r}\lambda s_j(z). \tag{14}$$

[19]Elasticities of prices with respect to capabilities are given by: $\frac{d\ln p_j}{d\ln\varphi} = \frac{\sigma-1-\alpha}{\gamma} < 0$ and $\frac{d\ln p_j}{d\ln\kappa} = \frac{\beta\theta-\sigma+1}{\gamma} > 0$, if $\beta > \frac{\sigma-1}{\theta}$. Note that this condition is more restrictive than the convexity assumption discussed above.

[20]This result is obtained by inserting the optimal investment levels in Equations (7) and (8) into the investment cost functions (1)

As investment outlays are a fraction of sales, firms with identical combined capability will spend the same amount on process and quality innovations. Equation (14) further implies that credit repayment in Equation (4) can also be expressed in terms of sales: $\lambda k_j = rf_j + \frac{\sigma-1}{\sigma}\lambda s_j(z)\left(\frac{1}{\beta}+\frac{1-\theta}{\alpha}\right)$.[21] The assumption that $\gamma > 0$ ensures that the fraction of sales which is spent on both process and quality innovations is less than one. Closely related to Equation (14), Sutton (2001) and Kugler and Verhoogen (2012) define the degree of quality differentiation as the ratio of R&D and advertising expenditures relative to firm size. In our setting, we compare the outlays for processes and quality innovations to obtain a measure that reflects the relative effectiveness of the two investments:

$$\frac{\frac{1}{\kappa}q_j^{\alpha}(z)}{\frac{1}{\varphi}e_j^{\beta}(z)} = \frac{(1-\theta)\beta}{\alpha}. \tag{15}$$

We denote this ratio as the scope for vertical product differentiation in a sector, as it reflects the relative importance of quality innovations compared to process innovations. Note that this ratio is independent of firm capabilities and only determined by exogenous parameters of the investment cost functions. Increases in α and θ make quality innovations less effective and reduce the relative expenditures for this investment type. Conversely, the ratio increases in β, which changes investment in favor of product upgrades.[22] In the following analysis, we will show that the effects of financial shocks on firm behavior and aggregate outcomes depend on the sectoral scope for vertical product differentiation.

2.3 Selection of firms

After describing the optimal behavior of firms that have access to external finance, we turn to the impact of moral hazard on the selection of firms into production and exporting. In order to ensure diligent behavior according to the incentive compatibility constraint (5), the financial sector grants credit only to those firms that have sufficiently high profits. Note that profits in Equation (13) are a function of the combined capability z. Hence, the binding financial constraint (5) determines a cutoff level of combined capability for (non-)exporters that is necessary to obtain external finance:

$$s_j(z_j) = \frac{\alpha\beta\sigma}{\gamma}\frac{r+b}{\lambda}f_j. \tag{16}$$

[21] See the Online Appendix for a more detailed discussion.

[22] The scope for vertical product differentiation in Equation (15) is closely related to the estimation of quality ladders proposed by Khandelwal (2010). In sectors with higher relative effectiveness, firms invest more in quality differentiation resulting in a larger demand shifter q. Conditional on prices, this translates into larger sales.

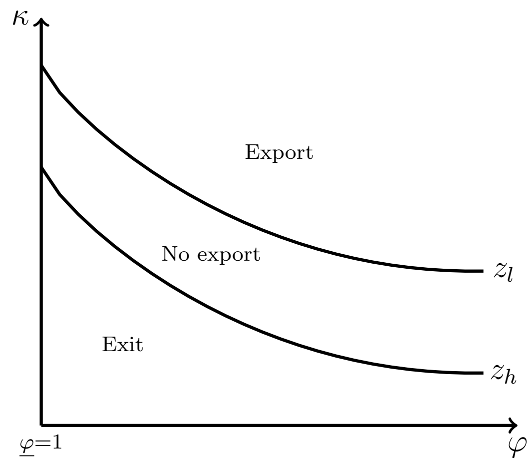


Figure 1: Selection pattern in the open economy

Note: The capability space above the marginal access curve z_h captures the set of active firms D as characterized in Section 3. The region above the curve z_l represents the set of exporters D_l.

Firms with $z > z_j$ are financially unconstrained and are active as (non-)exporters. If the private benefit b is equal to zero, financial frictions disappear and Equation (16) collapses to a zero-profit condition. Whenever the private benefit is positive ($b > 0$), moral hazard prevents external financing of profitable firms with low combined capability $z < z_j$. Similar to Melitz (2003), we impose a condition that fixed export costs f_l and variable trade costs τ are sufficiently high, $\frac{f_l}{f_h}\left(1+\tau^{1-\sigma}\right)^{\frac{-\alpha\beta}{\gamma}} > 1$, such that the most capable firms with $z \geq z_l$ export. Firms in the middle range of the (combined) capability distribution ($z_h \leq z < z_l$) sell only domestically, while the least efficient firms ($z < z_h$) have no access to external finance and exit.[23] Figure 1 depicts the selection pattern of firms in the two-dimensional capability space.

A larger private benefit b aggravates moral hazard, which increases the minimum cutoff level of the combined capability (16) that is required to meet incentive compatibility (5). This forces low capability firms to exit, corresponding to an upward-shift of marginal-access curves in Figure 1. Similar selection effects occur if fixed production costs go up. Our modeling approach is consistent with evidence that credit frictions lead to aggravated access to external finance and lower innovation activity, especially for smaller and less capable firms (Aghion et al., 2007; Beck et al., 2008; Paunov, 2012).[24]

Marginal firms, characterized by the cutoff levels of combined capability z_j, just meet

[23]See Appendix A.1 for an explicit solution of the selection condition.

[24]Note that Holmstrom and Tirole (1997) consider differences in wealth, whereas in our model firm-specific innovation capabilities determine access to external credit. Hence, we neglect the role of internal liquidity to overcome credit frictions as analyzed by Chaney (2016).

incentive compatibility (5) and are indifferent between diligent behavior and shirking, such that profits are equal to the probability-weighted private benefit: $\pi(z_j) = \frac{bf_j}{\lambda}$. These selection effects depend on the scope for vertical product differentiation. The elasticity of the marginal-access curve in the two-dimensional capability space is the negative inverse of Equation (15): $\frac{d\ln\kappa}{d\ln\varphi} = -\frac{\alpha}{\beta(1-\theta)}$. Hence, sectors with higher quality differentiation are characterized by flatter marginal-access curves in Figure 1. 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). From Equation (11), it follows that the optimal price depends on the relative importance of the two capabilities φ and κ. If the scope for vertical product differentiation (15) is high, then larger firms with higher quality-based capability κ invest more in quality upgrades resulting in higher prices consistent with empirical evidence (e.g. Manova and Zhang, 2012). 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 with unit values (Roberts and Supina, 1996; Foster et al., 2008). Accordingly, larger firms with higher cost-based capability φ invest more in process innovations that reduce marginal costs and prices.

3 Equilibrium in the open economy

In order to solve the equilibrium in the open economy, we characterize three key relationships. Analogous to single-attribute firm models as in Melitz (2003), we exploit that the combined capability z of a firm determines revenues and profits, as well as the selection into production and exporting. The first relation is a free entry condition to ensure that fixed entry costs f_e are equal to expected profits before firms know their capability draws:[25]

$$E[\pi] = \sum_j \psi_j E[\pi_j] = \sum_j \iint_{(\varphi,\kappa)\in D_j} \lambda\pi_j(\varphi,\kappa)\mu_s(\varphi,\kappa)d\varphi d\kappa = \frac{f_e}{\chi_s}, \tag{17}$$

where $\chi_s = \iint_{(\varphi,\kappa)\in D} g(\varphi,\kappa)d\varphi d\kappa$ is the probability of success, D denotes the set of all active firms in equilibrium, and D_j, with $j \in h, l$, are the regions of non-exporters and exporters respectively as depicted in Figure 1 (see the Online Appendix for technical details). The share of (non-)exporters is defined as $\psi_j = \frac{\chi_j}{\chi_s}$, and $\mu_s(\varphi,\kappa) = \frac{g(\varphi,\kappa)}{\chi_s}$ denotes the probability of

[25]Compared to Melitz (2003), we set the the exogenous probability of a death shock to one, which implies that firms invest after entry and earn profits for one period.

drawing a particular combination of capabilities, conditional on success. We abstract from external financing of fixed entry costs, such that expected profits are used to cover entry costs. In the Online Appendix, we show that relaxing this assumption generates additional effects without changing the main implications of our framework.[26]

The second and third key relations are factor market clearing conditions for both labor and capital. As labor is used for variable production costs, firms with higher combined capability z operate on a bigger scale and hence have larger labor demand, $l_j(z) = mc_j\left(x_j + 1_{\{j=l\}}\tau x_l^*\right) = \frac{\sigma-1}{\sigma}s_j(z)$. In equilibrium, the inelastic labor supply L has to satisfy the labor demand in the entry sector ($L_e = M_e f_e$), as well as the labor demand for production of non-exporters and exporters: $L = L_e + \sum_j L_j$. Aggregation of single labor requirements leads to the following labor market clearing condition:

$$\lambda L = M\left[\left(\frac{\gamma}{\alpha\beta} + \sigma - 1\right)\frac{\lambda\widetilde{s}}{\sigma} - r\widetilde{f}\right], \tag{18}$$

where $\widetilde{s} = \sum_j \psi_j \widetilde{s}_j$ denotes average sales, and $\widetilde{f} = \sum_j \psi_j f_j$ represents average fixed costs in the differentiated sector. This relationship is obtained by imposing aggregate stability such that the mass of successful entrants is equal to the number of active firms ($\chi_s M_e = M$).

A firm's capital demand follows from the budget constraint (3) and can be written as: $d_j(z) = f_j + \frac{\alpha\beta-\gamma}{\alpha\beta\sigma r}\lambda s_j(z)$. Aggregating over M firms leads to the total capital demand in the differentiated sector:

$$K = M\widetilde{d} = M\widetilde{f} + \frac{\alpha\beta-\gamma}{\alpha\beta\sigma r}M\lambda\widetilde{s}. \tag{19}$$

Combining Equations (18) and (19) implies that total income equals total sales in the economy, $I = (\lambda + r)L = M\lambda\widetilde{s} = \lambda S$, where we exploit that each worker owns one unit of capital, and the wage is normalized to one.

We obtain an explicit solution for the entry cutoff z_h by assuming that firms draw both innovation capabilities φ and κ from Pareto distributions with positive support over $[1,\infty]\times[1,\infty]$. To keep our model tractable, we further assume that the two capability draws are independently distributed. Relaxing this assumption would generate additional insights on the relative importance of cost-based and quality-based determinants for firm performance. If there is a positive correlation between the draws, then process and quality innovations are complements. In this case, firms with the same combined capability are less heterogeneous in terms of price setting and investment behavior. A negative correlation between the two capability draws implies that the heterogeneity between firms with the same size increases. In

[26] This extension is related to Bonfiglioli et al. (2018) who analyze the effect of financial frictions on endogenous firm entry in a heterogeneous firms model of trade.

Fig. 1, firms that are located on the same capability-curve will be more likely to concentrate on one investment (either quality or processes) and set different prices.

The probability of drawing a particular combination of φ and κ is given by: $g(\varphi, \kappa) = g_\varphi(\varphi) g_\kappa(\kappa)$ with $g_\kappa(\kappa) = \xi \kappa^{-\xi-1}$ and $g_\varphi(\varphi) = \vartheta \varphi^{-\vartheta-1}$, where ξ and ϑ are the shape parameters of the Pareto distributions. To achieve a well-defined equilibrium, we assume that the shape parameters are sufficiently large. We provide the technical details of the model's solution with Pareto distributed draws in the Online Appendix.

Condition 1 $\xi > \frac{\beta(1-\theta)(\sigma-1)}{\gamma}$ *and* $\vartheta > \frac{\alpha\xi}{\beta(1-\theta)}$.

As discussed in Section 2.2, we summarize the two capability draws in a single measure, the combined capability of a firm. Hence, sales and profits are a function of this combined capability and also follow a Pareto distribution.[27] This generates a reasonable approximation for the right tail of the observed distribution of firm sizes, as shown by empirical studies (Axtell, 2001; Eaton et al., 2011). Note that relaxing the assumption that the combined capability follows a Pareto distribution can lead to better approximations of the complete distribution of firm sales (Head et al., 2014).

4 Effects of credit frictions

In this section, we analyze the general equilibrium effects of credit frictions on firm and industry outcomes, on prices and welfare as well as on different measures of productivity. As we consider two symmetric countries, our analysis neglects implications of bilateral differences in financial development.[28]

4.1 Firm-level effects

We first show that credit frictions increase access barriers to finance and hence lead to an exit of the smallest firms. This adjustment at the extensive margin lowers competition and increases incentives to innovate for remaining firms. We further highlight that the scope for vertical product differentiation is decisive to determine which type of innovation gains relatively more.

Proposition 1 summarizes the effects of stronger credit frictions on the extensive and intensive margin (a) as well as on innovation (b).

[27] Our framework follows a large class of models that feature Pareto distributed firm sizes. See Arkolakis et al. (2012) for a discussion of related papers.

[28] Antràs and Caballero (2009) show how national differences in financial characteristics influence cross-border trade and capital flows. Crinò and Ogliari (2017) find that financial imperfections are an important determinant of variation in product quality across countries and industries.

Proposition 1 *(a) Stronger credit frictions (a higher private benefit b) lead to an exit of firms (M falls) and raise the cutoff level of combined capability z_h (extensive margin). Average sales ($\lambda\widetilde{s}$) rise: $d\ln M/d\ln b < 0$, $d\ln z_h/d\ln b > 0$, and $d\ln(\lambda\widetilde{s})/d\ln b > 0$. (b) Innovative activity in both types of innovation is boosted.*

Proof. See Appendix A.2. ■

In our framework, stronger credit frictions imply an increase in b. Larger private benefits enhance incentives of borrowers to misbehave and can be interpreted as a worsening of investor protection or weaker enforceability of credit contracts. As a consequence, investors demand more pledgeable income, which puts a stronger restriction on incentive compatibility (and hence on entry) in Equation (5). As a consequence, fewer firms are active in the market (M falls), and the smallest firms exit (reflected in the increase of the cutoff z_h). Since the size of the market $I = (\lambda + r) L$ is essentially unaffected by a change in b and equal to $M\lambda\widetilde{s}$, a reduction in the number of firms M leads to an equiproportional increase in the average size of firms $\lambda\widetilde{s}$: $d\ln(\lambda\widetilde{s})/d\ln b = -d\ln M/d\ln b$. This is in line with evidence that credit frictions especially hurt smaller firms and restrict market access (Aghion et al., 2007; Beck et al., 2008).[29]

The reduction in the number of firms is also driving the impact on innovation. Since remaining firms are larger and both types of innovation are increasing in firm size according to Equation (14), innovation activity of remaining producers clearly rises: $\beta(d\ln e_j/d\ln b) = \alpha(d\ln q_j/d\ln b) > 0$.

4.2 Price and welfare effects

Agents derive utility from the consumption of goods and exert effort by foregoing private benefits. We assume that preferences are separable in consumption and private benefits. Given that incentive compatibility in Equation (5) is satisfied, there is no consumption of private benefits in equilibrium.[30] Welfare equals real income per consumer and can be written as a function of the quality-adjusted price index: $X = IP^{-1}$. Welfare clearly falls in response to an increase of financial frictions:

Proposition 2 *An increase in credit frictions (higher b) reduces welfare unambiguously: $d\ln X/d\ln b < 0$. Prices, however, are NOT a unique indicator of welfare. Depending on the*

[29]Credit frictions also have negative effects on the decision to export (Berman and Héricourt, 2010; Minetti and Zhu, 2011). During the financial crisis 2008-2009, the number of exported varieties has declined, which can be explained by a credit shock that aggravates access to finance (Unger, 2021).

[30]We follow Egger and Keuschnigg (2015, 2017) who consider real income as welfare measure in related frameworks with credit frictions and moral hazard.

scope for quality differentiation ($\alpha \lesseqgtr \beta\theta$), prices will rise or fall in response to an increase in credit frictions ($d \ln p_j / d \ln b \gtreqless 0$), leading to either a negative or a positive correlation between prices and welfare ($\frac{d \ln X}{d \ln b} / \frac{d \ln p_h}{d \ln b} \lesseqgtr 0$).

Proof. See Appendix A.2. ■

Welfare is affected through two channels: On the one hand, there is a loss in product variety that tends to reduce welfare. On the other hand, there is a selection effect that tends to increase welfare through an increase in average productivity. In our framework, the product variety always dominates and welfare falls.

With CES demand, the effect of prices depends on the innovation activities of firms. Process innovation tends to reduce prices, while quality innovations tend to increase prices. From (11) and proposition 1 we obtain $\frac{d \ln p_j}{d \ln b} = \theta \frac{d \ln q_j}{d \ln b} - \frac{d \ln e_j}{d \ln b} = \left(\theta - \frac{\alpha}{\beta}\right) \frac{d \ln q_j}{d \ln b}$. And since $d \ln q_j / d \ln b$ is unambiguously positive, the overall effect on prices depends on $\theta - \alpha/\beta$, and thus on the scope for quality differentiation.

This difference in the price response leads to an important ambiguity in the correlation between welfare and prices:

$$\frac{d \ln X}{d \ln b} / \frac{d \ln p_h}{d \ln b} = \frac{\gamma}{\sigma - 1} \frac{1}{\alpha - \beta\theta} \gtreqless 0. \tag{20}$$

The welfare effect of credit frictions is obtained after adjusting the price response by a correction term that depends on the scope for vertical product differentiation. If the scope for quality differentiation is relatively high ($\alpha < \beta\theta$), then stronger credit frictions raise prices. In this case, the responses of prices and welfare are negatively correlated. If quality differentiation is low ($\alpha > \beta\theta$), credit frictions reduce prices and consequently prices and welfare are positively correlated. We further investigate the relation between prices and welfare in our counterfactual analysis presented in Section 5.

4.3 Productivity effects

We further show how differential effects of credit frictions on investments and prices influence firm-level productivity. In a first step, we define a quantity-based productivity measure (TFPQ) as the ratio of output relative to total factor input:

$$\Phi_j^Q (\varphi, \kappa) = \frac{x_j (\varphi, \kappa)}{l_j (z) + \frac{r}{\lambda} d_j (z)}, \tag{21}$$

where $l_j (z) = \frac{\sigma - 1}{\sigma} s_j (z)$ denotes variable production costs, and $\frac{r}{\lambda} d_j (z)$ represents capital costs for fixed and endogenous innovations. Note that capital costs are weighted by $1/\lambda$ as investors take into account that credit repayment occurs with a probability smaller than one and hence demand a larger return to satisfy the participation constraint in Equation (4). The expression in Equation (21) is our measure of physical efficiency. In many empirical studies, physical output data at the firm level are not directly observable or difficult to compare because of different units of measurement. A common approach is the use of revenue-based productivity measures (TFPR) to estimate production functions (Forlani et al., 2016; Garcia-Marin and Voigtländer, 2019). In our model, TFPR is given by revenues over total factor costs, where the wage is normalized to one:

$$\Phi_j^R(z) = \frac{s_j(z)}{l_j(z) + \frac{r}{\lambda} d_j(z)} = \Phi_j^Q(\varphi, \kappa)\, p_j(\varphi, \kappa). \tag{22}$$

Note that TFPR monotonically increases in a firm's combined capability $z = \varphi^{\alpha}\kappa^{\beta(1-\theta)}$, which follows immediately from Equation (22): $\frac{d\Phi_j^R(z)}{dz} = \frac{\frac{r}{\lambda} f_j}{\left[l_j(z) + \frac{r}{\lambda} d_j(z)\right]^2} \frac{ds_j(z)}{dz} > 0$. However, this is not the case for TFPQ. The comparison of Eqs. (21) and (22) shows that revenue-based productivity is an insufficient indicator of firm performance in the presence of two types of capability. To see this, we compare two firms that have identical combined capability z and hence are located on the same iso-z curve as shown in Fig. 1, but differ in their capability draws φ and κ. Observing TFPR in Equation (22) would inaccurately suggest that both firms are equally productive despite the fact that they differ in their physical efficiency. If one firm has a high κ-draw compared to the other, part of the effect on TFPR is driven by a larger price: this firm invests more in quality innovations which increases marginal production costs and hence the price of the good. In this case, the underlying TFPR is higher compared to a firm with high φ and thus larger investment in processes that reduce the price and increase demand. If the scope for vertical product differentiation is high, the upward bias of TFPR compared to TFPQ becomes more severe as prices increase in firm size.

This distinction between TFPQ and TFPR is crucial to understand the implications of credit frictions across industries. We consider the average levels of the two productivity measures in Equation (21) and (22):

$$\tilde{\Phi}_j^R = \frac{\frac{\sigma}{\sigma-1}\left(\frac{\tilde{z}_j}{z_j}\right)^{\frac{\sigma-1}{\gamma}}}{\left(\frac{\sigma}{\sigma-1} - \upsilon\right)\left(\frac{\tilde{z}_j}{z_j}\right)^{\frac{\sigma-1}{\gamma}} + \frac{r\upsilon}{r+b}}; \; \tilde{\Phi}_j^Q = \frac{\tilde{\Phi}_j^R}{\tilde{p}_j}. \tag{23}$$

Equation (23) shows that credit frictions influence productivity measures through two channels. First, there is a positive reaction of TFPR as the private benefit induces exit of firms and hence increases average sales (compare Proposition 1): $\frac{d\ln\tilde{\Phi}_j^R}{d\ln b} = \frac{rf_j}{\lambda\tilde{l}_j + r\tilde{d}_j}\frac{b}{r+b} > 0$, where $\frac{rf_j}{\lambda\tilde{l}_j + r\tilde{d}_j}$ denotes the share of fixed production costs in average costs.

Second, productivity is affected by endogenous adjustments of prices. The effects of credit frictions on TFPQ can be decomposed into the reaction of TFPR and the change in the average price:

$$\frac{d\ln\tilde{\Phi}_j^Q}{d\ln b} = \underbrace{\frac{d\ln\tilde{\Phi}_j^R}{d\ln b}}_{>0} - \frac{d\ln\tilde{p}_j}{d\ln b} \lesseqgtr 0. \tag{24}$$

Proposition 3 *If the scope for vertical product differentiation is relatively high ($\alpha < \beta\theta$), the reaction of revenue productivity (TFPR) to credit frictions is larger compared to quantity productivity (TFPQ). Whenever $\frac{\beta\theta-\alpha}{\alpha\beta} > \frac{rf_j}{\lambda\tilde{l}_j + r\tilde{d}_j}$, credit frictions reduce TFPQ and welfare, whereas there is an increase of TFPR.*

Proof. See Appendix A.2. ■

Our analysis highlights that inferring the implications of credit frictions from price effects leads to inaccurate conclusions if general equilibrium adjustments of innovations are not taken into account.[31] Whenever credit frictions aggravate access to external finance, prices react positively in sectors with large scope for vertical product differentiation as innovation activities become more concentrated and hence remaining producers shift resources relatively more to quality innovations. While average TFPR increases due to exit of low capability firms, the positive price reaction leads to a negative adjustment of TFPQ whenever the scope for quality differentiation is sufficiently high. If the latter is low, there is a relative gain for process innovations compared to quality innovations which leads to negative effects of credit frictions on prices. Consequently, both TFP measures increase on average, while TFPQ shows a stronger response due to the negative price effect. In the following section, we quantify the effects of credit frictions on prices, productivity measures as well as welfare, and relate them to the scope for vertical product differentiation across sectors. Before we turn to the quantitative analysis, we discuss the impact of the interest rate in our framework.

Change in interest rate. In contrast to stronger credit frictions, a higher borrowing rate reduces process and quality innovations of all firms. Additionally, there is a rise in the cutoff level, which further lowers innovation activity of surviving producers, as the competitive advantage relative to the marginal firm shrinks (see Appendix A.3 for technical details).

[31] Table 3 in Appendix A.4 summarizes the effects of financial shocks in partial and general equilibrium. Note that the private benefit b has no direct impact on innovation in partial equilibrium, as the moral hazard problem affects incentives to innovate only through a change in the number of firms. This assumption could be relaxed by assuming that private benefits and credit costs are positively correlated. Related to this, we extend the model in the Online Appendix by allowing for private benefits proportional to total loan size.

Compared to credit frictions, there is a reversed impact of the scope for vertical product differentiation (15) on prices in Equation (11). If the scope for vertical product differentiation is low, higher credit costs reduce process innovations relatively more than quality investments, which increases firm-level prices. As a consequence, both TFPQ and TFPR decrease. If the scope for vertical product differentiation in a sector is relatively high ($\alpha < \beta\theta$), then credit costs reduce prices and TFPR due to a relatively stronger decrease in quality innovations. This price reaction counteracts the direct impact of reduced investments on TFPQ. Hence, the key result from this comparative static analysis is that the relationship between credit conditions, prices and welfare depends on the nature of the financial shock and the scope for vertical product differentiation.

Endogenous interest rate. As discussed in Section 2, our analysis is based on the assumption of a fixed interest rate. Hence, stronger credit frictions b reduce capital demand due to exit of firms without affecting borrowing costs. We discuss that the main implications of our model remain valid if we relax the assumption of a fixed interest rate, while providing technical details in the Online Appendix. We impose a capital market clearing condition such that the inelastic capital supply K equals aggregate capital demand in Equation (19). With inelastic capital supply, an additional effect occurs as stronger credit frictions induce a reduction in capital demand, which lowers the interest rate. This indirect effect does not overturn the negative impact of credit frictions on the number firms and the associated increase in the average efficiency (see Proposition 1). Most importantly, allowing for endogenous interest rate adjustments does not change the main implications with respect to innovation choices and price effects. The additional reduction in credit costs intensifies the positive effects of credit frictions on innovation choices. While the magnitude of price reactions is changed, the direction of the effects is still determined by the scope for vertical product differentiation (compare Proposition 2). The reduction in the interest rate leads to opposing effects on welfare as a negative income effect is counteracted by the fact that borrowing costs for investments are reduced. Compared to Proposition 2, we can still show that welfare losses occur if credit frictions are sufficiently strong. The productivity effects in Proposition 3 also remain valid as stronger credit frictions reduce borrowing costs which intensifies the positive effect on TFPR beyond the selection effect. As discussed in the previous subsection, adjustments of the interest rate also reinforce the reaction of prices to credit frictions without changing the direction of the effects. Hence, the price reaction in Equation (24) is still determined by the scope for vertical product differentiation (see the Online Appendix for technical details).

5 Quantitative analysis of credit frictions

We have shown that the the effects of credit frictions depend on the scope for vertical product differentiation in a sector. Using data from the World Bank's Enterprise Surveys for Columbia in 2016, this section quantifies implications for prices, productivity measures, and welfare separately for each sector. We calibrate the model with two types of innovation to match sectoral characteristics related to investment, exporting, and financial development.[32] To evaluate the importance of the interaction between credit frictions and endogenous innovations, we then compare our results to three counterfactual scenarios that capture existing classes of models in the literature.

Quantifying the effects of credit frictions in our framework requires values for the following parameters by sector: (i) the elasticity of substitution σ, (ii) the investment cost parameters α, β, and θ, (iii) the variable trade costs (τ) and fixed trade costs relative to domestic fixed costs (f_x/f_d), as well as (iv) the private benefit b. Accordingly, we proceed in four steps to calibrate the model to observed moments at the sectoral level. In a first step, we exploit that the labor share in sales, $l_j(z)/s_j(z) = \frac{\sigma-1}{\sigma}$, is solely determined by the elasticity of substitution σ (compare Section 3). Note that this feature is common in models with CES preferences. Hence, we choose the elasticity of substitution σ to match the ratio of annual labor costs to total sales by sector. Second, we follow Bustos (2011) as well as Kugler and Verhoogen (2012) and use average annual expenditures on machinery, vehicles, and equipment as a proxy for process innovations, as well as annual expenditures on research and development activities as a proxy for quality innovations. We target the corresponding investment ratios in Equation (14) and obtain sector-specific values of the investment cost parameter α and β. Note that we obtain values for α by sector conditional on the chosen value for θ, which is set to 0.783 for all sectors. This value is consistent with gravity estimates on quality differentiation from Flach and Unger (2022).[33] Third, following the estimate in Anderson and van Wincoop (2004), we assume that $\tau = 1.7$, and we set the Pareto shape parameter $\xi = 3$, which corresponds to Crozet and Koenig (2010). We target the share of exporters by sector:

$$\psi_l = \left(\frac{f_l}{f_h}\right)^{-\frac{\xi\gamma}{\beta(\sigma-1)(1-\theta)}} \left(1+\tau^{1-\sigma}\right)^{\frac{\alpha\xi}{(\sigma-1)(1-\theta)}}, \tag{25}$$

which allows us to obtain the implied ratio of fixed export costs to domestic fixed costs.[34] As

[32]This approach is related to studies that use intra-industry trade models to estimate effects of trade shocks separately by industry, see e.g. Crozet and Koenig (2010), Blaum et al. (2018), and Flach and Unger (2022).

[33]See the Online Appendix for technical details. We show that our results are robust to different values of θ and to differences in the productivity distribution at the end of this section.

[34]Additional targeting of trade shares by sector would allow to obtain sector-specific estimates of variable

a last step, it follows from Equation (19) that the capital amount relative to sales is given by $\frac{K}{S} = \frac{\widetilde{f}}{\lambda \bar{s}} + \frac{\alpha\beta - \gamma}{\alpha\beta\sigma r}$. We show in the Online Appendix that Equation (19) can be solved for the private benefit b, which depends negatively on the ratio of credit over sales, and is further affected by exogenous model's parameters as obtained from the previous calibration steps. Intuitively, a larger credit to sales ratio reflects better access to finance and hence reduces the degree of credit frictions measured by the parameter b. We use the ratio of private credit to GDP (0.471 for Colombia in 2016, according to the World Bank's Financial Development Indicators) as the empirical counterpart for the credit to sales ratio in our model. While this measure is country-specific, the procedure takes into account heterogeneity in credit demand across sectors captured by differences in investment intensity and relative export costs. This allows us to compute sector-specific values for the private benefit b (we additionally take into account differences in access to external finance across sectors in the robustness checks). Table 1 summarizes the targeted moments and the implied parameter values by sector (see the Online Appendix for technical details of the calibration).

Table 1: Matched moments and parameter estimates by sector

Sector	Code	Matched moments by sector				Parameter estimates by sector				
		labor/ sales	quality/ sales	process/ sales	share of exporters	σ	α	β	f_l/f_h	b
Food	15	0.189	0.027	0.099	0.202	1.233	1.519	1.903	2.162	0.967
Textiles	17	0.307	0.008	0.074	0.357	1.443	8.104	4.176	1.945	0.565
Garments	18	0.287	0.015	0.048	0.425	1.402	4.018	5.981	1.929	0.585
Leather	19	0.314	0.005	0.082	0.500	1.459	13.090	3.811	1.946	0.557
Wood	20	0.248	0.012	0.021	0.333	1.330	4.379	11.974	1.903	0.634
Publishing, printing	22	0.293	0.005	0.170	0.308	1.414	11.624	1.721	2.199	0.795
Chemicals	24	0.217	0.056	0.076	0.409	1.278	0.848	2.874	2.166	0.876
Plastics and rubber	25	0.168	0.039	0.097	0.429	1.202	0.931	1.740	2.186	1.047
Non-metal. mineral prod.	26	0.191	0.017	0.063	0.556	1.235	2.447	3.004	2.028	0.855
Fabricated metal products	28	0.273	0.054	0.077	0.286	1.375	1.091	3.542	2.156	0.716
Machinery and equipment	29	0.289	0.050	0.075	0.323	1.406	1.258	3.830	2.116	0.659
Electronics	31	0.267	0.008	0.030	0.286	1.364	6.916	8.894	1.895	0.601
Precision instruments	33	0.196	0.009	0.109	0.500	1.243	4.555	1.792	2.102	0.939
Transport machines	34	0.157	0.006	0.033	0.500	1.186	5.728	4.696	1.971	0.859
Furniture	36	0.190	0.032	0.060	0.333	1.235	1.281	3.179	2.076	0.874
Construction Section F	45	0.266	0.004	0.051	0.070	1.362	12.947	5.233	1.928	0.630
Wholesale	51	0.145	0.010	0.064	0.228	1.170	3.023	2.255	2.050	0.962
Retail	52	0.171	0.029	0.243	0.038	1.206	1.279	0.701	2.744	1.760
Hotel and restaurants	55	0.247	0.006	0.069	0.300	1.328	9.622	3.595	1.974	0.707
Transport Section	60	0.370	0.032	0.324	0.129	1.587	2.486	1.141	3.837	1.313
IT	72	0.390	0.094	0.046	0.300	1.640	0.902	8.409	2.179	0.349
Average		0.246	0.025	0.091	0.324	1.338	4.669	4.021	2.166	0.822

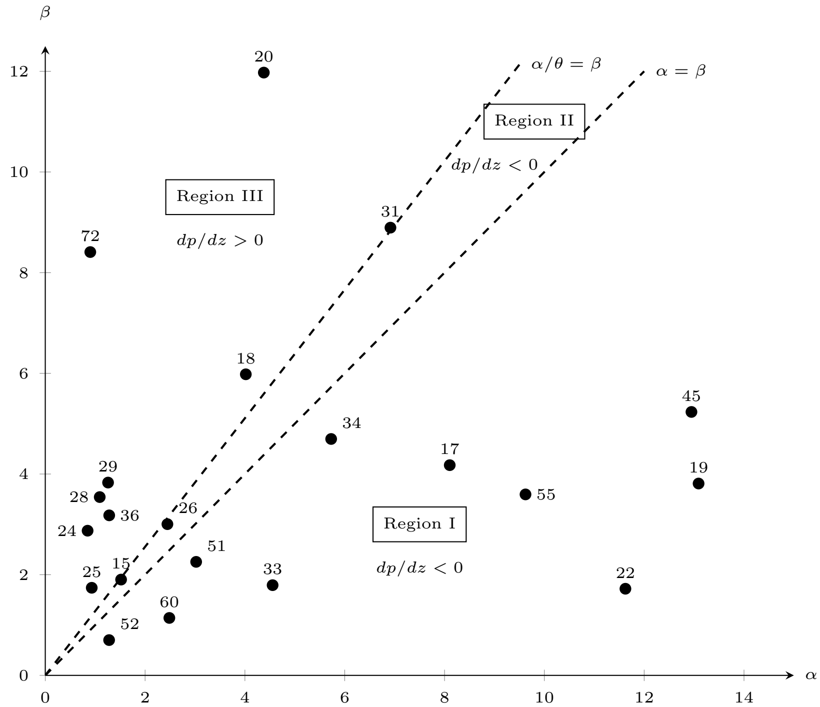
Calibration of model for Colombia. Data: World Bank Enterprise Surveys 2017, Financial Development Indicators.

trade costs. While this step is important when estimating trade shocks, see e.g. Melitz and Redding (2015), we abstract from it and show in the robustness checks that our results do hardly change with variation in variable trade costs. The reason is that changes in variable trade costs imply opposite adjustments of fixed export costs to match the share of exporters in Equation (25), while the impact of credit frictions depends on the joint size of variable and fixed trade costs.

We additionally quantify three counterfactual scenarios that reflect existing classes of models in the literature. The first category features cost-based sorting as in Melitz (2003) without endogenous innovations. Models in this category are not able to explain a positive relation between firm size and prices, and do not capture that innovation choices react endogenously to financial shocks. Our framework nests these models as a special case if investment cost parameters α and β become prohibitively large such that innovations are driven down to zero. Without endogenous innovations, firms only differ in cost-based capability φ that resembles the exogenous productivity draw in Melitz (2003). In this case, we target the labor-to-sales ratio, the share of exporters, and private credit to GDP to obtain values for the elasticity of substitution σ, fixed trade costs f_l/f_h, and the private benefit b. Second, if only β becomes prohibitively large, our framework nests models that feature quality-based sorting with endogenous quality innovations, such that firm size is positively correlated with prices (Manova and Zhang, 2012; Kugler and Verhoogen, 2012). We calibrate this second category of models by targeting the ratio of expenditures on research and development relative to sales, while neglecting process innovations, such that $\varphi = 1$ for all firms. In contrast, the third counterfactual scenario represents a situation with a very large parameter α, leading to cost-based sorting ($z = \varphi$) with only process innovations that are governed by β. Parameter estimates of the benchmark cases and technical details of the counterfactual scenarios are provided in the Online Appendix.

Figure 2 illustrates the combination of investment cost parameters α and β by sector, as reported in Table 1. Whenever $\alpha = \beta$ ($\alpha = \theta\beta$), the reactions of relative investments (prices) equal zero, as counteracting cost and quality effects offset each other (see Proposition 2). This allows to distinguish three regions depending on the combination of α and β. Figure 2 highlights that it is important to take into account both dimensions. For example, the sectors textiles (17) and machinery and equipment (29) show a similar intensity of process innovations (reflected by β), while quality differentiation is much more important for machinery and equipment, leading to a lower value of α compared to textile. The table below Figure 2 summarizes the effects of both financial shocks on endogenous outcomes across regions. Note that these effects depend on the scope for vertical product differentiation, which is determined by the relative size of the investment cost parameters in Equation (15).[35] Sectors in Region I show a relatively low scope for quality differentiation. Stronger credit frictions reduce prices due to a relative shift of resources towards process innovations, leading

[35]We show in Figure 1 of the Online Appendix that both the scope for vertical product differentiation and the ratio of quality innovations to sales are positively correlated with the R&D intensity of Kugler and Verhoogen (2012). Note, however, that these measures are not perfectly comparable, as Equation (15) relates process to quality innovations, while Kugler and Verhoogen (2012) consider the ratio of R&D and advertising expenditures relative to sales.



Reaction of endogenous variables to increase in credit frictions b

	Rel. investment e/q	Price	TFPR	TFPQ
Region I	$+$	$-$	$+$	$+$
Region II	$-$	$-$	$+$	$+$
Region III	$-$	$+$	$+$	$-/+$

Reaction of endogenous variables to increase in credit costs r

	Rel. investment $\frac{e}{q}$	Price	TFPR	TFPQ
Region I	$-$	$+$	$-$	$-$
Region II	$+$	$+$	$-$	$-$
Region III	$+$	$-$	$-$	$-/+$

Figure 2: Effects of financial shocks depending on investment parameters; Region I: low quality, high level of process innovations; Region II: intermediate levels of innovations; Region III: high quality differentiation, low level of process innovations. Financial shocks lead to welfare losses in all regions, while the relation between firm size and prices is negative in Regions I and II ($dp/dz < 0$), and positive in Region III ($dp/dz > 0$).

to a positive reaction of both productivity measures. Instead, sectors within Region III with high quality differentiation, show less positive or even negative responses of average TFPQ to credit frictions, whereas there is a positive reaction of average TFPR. In the intermediate case of Region II, relative investments follow the responses of highly differentiated sectors, whereas changes in prices and productivity are not reversed compared to Region I.

While this illustration only shows the direction of effects, we now turn to the quantitative importance of the responses. We explore the effects of a one percent increase in credit frictions b. Table 2 reports the corresponding elasticities of prices, welfare and average productivity measures as summarized in Propositions 2 and 3.[36] In case of a model without endogenous

[36]The explicit solutions of the elasticities of prices, welfare and productivity are shown in Equations (A8),

Table 2: Effects of credit frictions on prices, average productivity measures, and welfare

		A. No innovation				B. Only process innovations			
Sector	Code	Price	TFPR	TFPQ	Welfare	Price	TFPR	TFPQ	Welfare
Food	15	-0.305	0.275	0.580	-1.346	-0.308	0.250	0.558	-1.564
Textiles	17	-0.246	0.144	0.390	-0.288	-0.198	0.204	0.402	-0.769
Garments	18	-0.260	0.166	0.426	-0.399	-0.130	0.218	0.349	-0.881
Leather	19	-0.234	0.133	0.366	-0.245	-0.237	0.206	0.443	-0.781
Wood	20	-0.284	0.209	0.493	-0.680	-0.062	0.246	0.308	-1.141
Publishing, printing	22	-0.258	0.161	0.419	-0.367	-0.275	0.141	0.416	-0.540
Chemicals	24	-0.296	0.243	0.538	-0.976	-0.353	0.288	0.642	-1.728
Plastics and rubber	25	-0.310	0.298	0.608	-1.684	-0.356	0.271	0.628	-1.901
Non-metal. mineral prod.	26	-0.302	0.271	0.573	-1.308	-0.351	0.322	0.673	-2.229
Fabricated metal products	28	-0.272	0.183	0.454	-0.495	-0.245	0.231	0.476	-1.012
Machinery and equipment	29	-0.261	0.164	0.425	-0.389	-0.222	0.218	0.440	-0.890
Electronics	31	-0.275	0.189	0.464	-0.534	-0.083	0.229	0.312	-0.984
Precision instruments	33	-0.302	0.266	0.567	-1.239	-0.317	0.235	0.552	-1.406
Transport machines	34	-0.312	0.311	0.623	-1.916	-0.194	0.352	0.546	-2.650
Furniture	36	-0.305	0.274	0.579	-1.328	-0.300	0.313	0.613	-2.038
Construction Section F	45	-0.268	0.184	0.452	-0.528	-0.138	0.218	0.356	-0.931
Wholesale	51	-0.316	0.325	0.641	-2.189	-0.432	0.352	0.784	-2.969
Retail	52	-0.305	0.291	0.596	-1.620	-1.046	0.188	1.234	-1.263
Hotel and restaurants	55	-0.285	0.211	0.496	-0.690	-0.246	0.254	0.500	-1.242
Transport Section	60	-0.158	0.068	0.226	-0.046	-0.336	0.052	0.388	-0.122
IT	72	-0.119	0.045	0.164	-0.008	-0.072	0.125	0.198	-0.331
Average		-0.270	0.210	0.480	-0.870	-0.281	0.234	0.515	-1.303

		C. Only quality innovation				D. Two types of innovation			
Sector	Code	Price	TFPR	TFPQ	Welfare	Price	TFPR	TFPQ	Welfare
Food	15	0.397	0.292	-0.105	-1.590	-0.005	0.257	0.262	-1.737
Textiles	17	0.064	0.193	0.129	-0.684	-0.051	0.181	0.232	-0.710
Garments	18	0.133	0.209	0.076	-0.765	0.010	0.199	0.189	-0.819
Leather	19	0.039	0.187	0.148	-0.658	-0.072	0.175	0.246	-0.675
Wood	20	0.128	0.242	0.115	-1.058	0.036	0.236	0.200	-1.108
Publishing, printing	22	0.045	0.205	0.160	-0.780	-0.226	0.171	0.397	-0.799
Chemicals	24	0.709	0.258	-0.451	-1.047	0.253	0.231	-0.022	-1.316
Plastics and rubber	25	0.665	0.307	-0.358	-1.792	0.131	0.268	0.137	-2.038
Non-metal. mineral prod.	26	0.243	0.293	0.049	-1.639	-0.006	0.272	0.278	-1.734
Fabricated metal products	28	0.520	0.214	-0.306	-0.645	0.169	0.191	0.022	-0.849
Machinery and equipment	29	0.440	0.202	-0.238	-0.573	0.134	0.181	0.047	-0.749
Electronics	31	0.079	0.227	0.148	-0.935	0.000	0.220	0.220	-0.966
Precision instruments	33	0.129	0.290	0.161	-1.630	-0.185	0.256	0.441	-1.680
Transport machines	34	0.106	0.330	0.223	-2.322	-0.035	0.318	0.353	-2.362
Furniture	36	0.473	0.290	-0.183	-1.531	0.134	0.268	0.134	-1.706
Construction Section F	45	0.042	0.228	0.186	-0.964	-0.050	0.218	0.268	-0.982
Wholesale	51	0.204	0.340	0.136	-2.538	-0.090	0.315	0.405	-2.612
Retail	52	0.475	0.306	-0.169	-1.830	-0.505	0.198	0.703	-2.028
Hotel and restaurants	55	0.058	0.245	0.187	-1.108	-0.081	0.229	0.310	-1.131
Transport Section	60	0.190	0.139	-0.051	-0.299	-0.297	0.078	0.375	-0.392
IT	72	0.553	0.120	-0.433	0.015	0.150	0.100	-0.050	-0.241
Average		0.271	0.244	-0.027	-1.161	-0.028	0.217	0.245	-1.268

Simulated effects of credit frictions in case of benchmark model without endogenous innovations (Panel A), only process innovation (B), only quality innovation (C), and for two types of innovation(D).

innovations (Panel A), this leads to negative price responses across sectors, driven by exit of low productivity firms that charge higher prices. The negative price reaction implies that the effect on average TFPR is considerably attenuated compared to average TFPQ (0.210 vs. 0.480 on average across sectors). A similar pattern occurs when allowing for only

(A10), and (A13) in Appendix A.2.

process innovations (Panel B), as remaining firms increase process innovations and hence lower prices due to firm exit. Consequently, the positive reaction of TFPR is attenuated by 55% compared to TFPQ on average across sectors (0.234 vs. 0.515). In contrast, Panel C of Table 2 shows that average prices react positively in all sectors when only endogenous quality innovations are taken into account. Note that the reaction of TFPR is on average comparable in magnitude to Panel B as credit frictions force low capability firms to exit, resulting in similar effects on the extensive margin in both cases. However, the positive price adjustments lead to substantially lower responses of average TFPQ, which even turns negative in 9 out of 21 sectors where quality differentiation is high.

We compare these benchmark cases to the effects of credit frictions in our framework with two types of innovation (Panel D). As highlighted in Proposition 2, the price reaction is positive in sectors with a large scope for vertical product differentiation, while a negative price response occurs if process innovations are relatively more important. Figure 3 illustrates that the price responses, as reported in Panel D of Table 2, are positively correlated with the scope for vertical product differentiation. In sectors with high quality differentiation (e.g. machinery and equipment, chemicals), the positive price effect attenuates the response of average TFPQ compared to TFPR (see Proposition 3). Instead, sectors with limited importance of quality innovations (e.g. leather, textiles) show a stronger reaction of TFPQ (see Panel (b) of Figure 3). To interpret the magnitude of the effects based on the elasticities reported in Table 2, note that a 1% decrease of the credit to GDP ratio, starting from the initial value of 0.471 in 2016, corresponds to an increase of the private benefit b by 3.09%. From the average elasticities in Table 2 follows that average TFPQ increases by 0.75% $(= 0.245 * 3.09)$, and welfare decreases by 3.92% $(= -1.268 * 3.09)$ across sectors. Table 2 further shows that accounting for endogenous innovations increases the magnitude of welfare losses by 45% on average across sectors compared to a model without endogenous innovations (-0.87 vs. -1.27).

Discussion of results. The quantification of the model shows two important implications: First, the reactions of TFPQ and TFPR to credit frictions can differ substantially when both process and quality innovations are taken into account. Second, the price reaction is no good predictor for welfare effects of financial shocks. While the scope for vertical product differentiation determines whether prices rise or fall, all sectors face welfare losses from stronger credit frictions driven by lower product variety (see Proposition 2).[37] Note that the welfare response according to Equation (20) can be interpreted as a change in the inverse

[37]One exception is the IT sector in case of only quality innovations (see Panel C of Table 2), where the negative variety effect captured by the first term in Equation (A10) is relatively small (-0.375). The efficiency gain (0.390), reflected by the second term in Equation (A10), outweighs the direct effect leading to a slightly positive welfare response of 0.015.

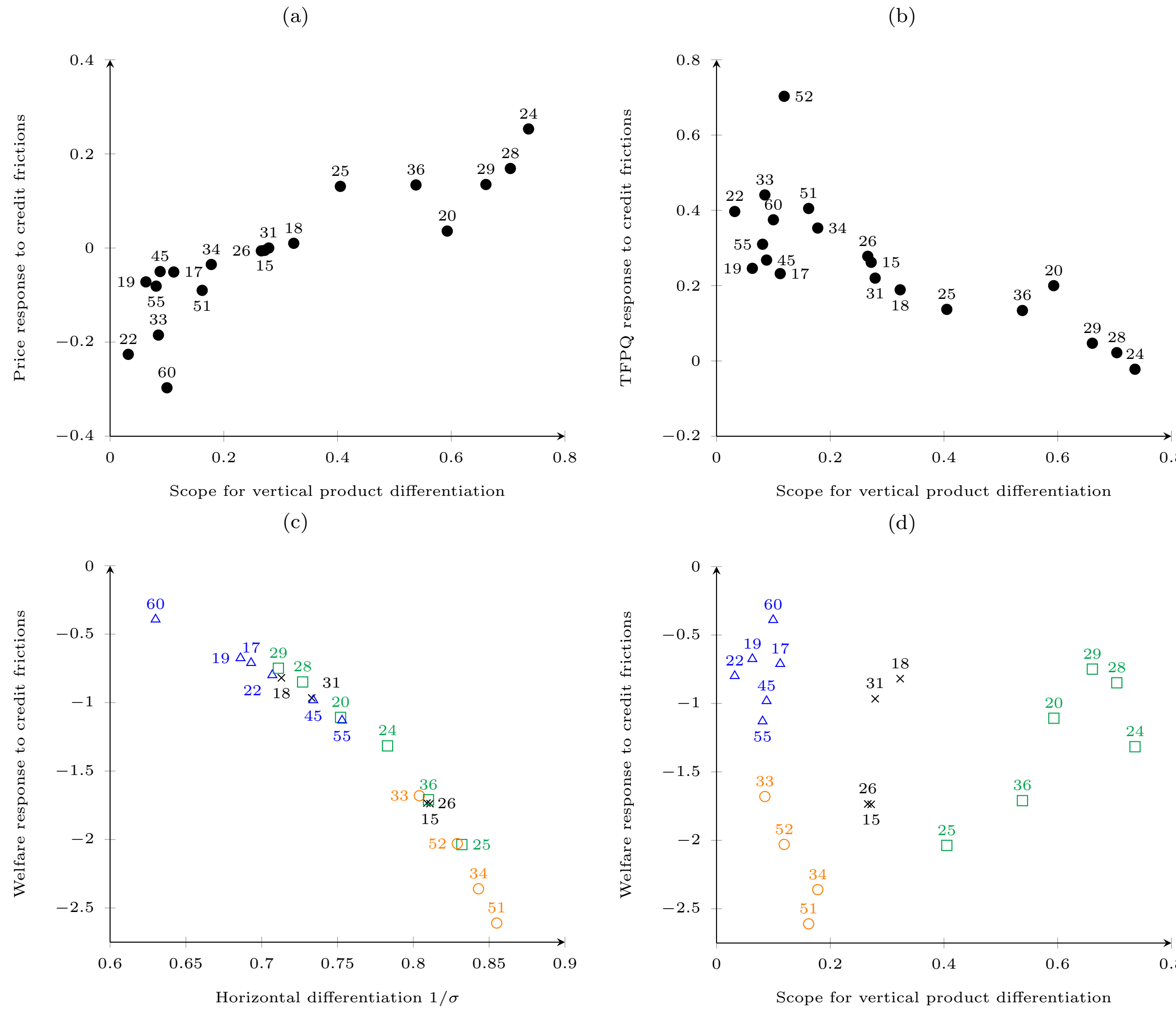


Figure 3: Relation of scope for vertical product differentiation with price elasticity to credit frictions (panel a), elasticity of TFPQ to credit frictions (b). The correlation coefficients in the two panels are (a) 0.772, and (b) -0.774, which are both significant at the 1% level. Panels (c) and (d) relate the elasticity of welfare with respect to credit frictions to horizontal differentiation and the scope for vertical product differentiation. The panels distinguish sectors with low horizontal and vertical product differentiation (marked by triangles), sectors with low vertical but high horizontal differentiation (marked by circles), and sectors with high vertical differentiation (squares).

quality-adjusted price index for each sector. Prices and welfare responses move in the same direction if quality innovations are not taken into account. However, in our framework with two types of innovation a correction term following Equation (20) is required to infer welfare implications from price reactions. This correction term reflects the difference between price and welfare effects in Panel D of Table 2.

Only in the model variant without innovations, responses of prices and welfare show a strong positive correlation. In contrast, the presence of investments does not allow to infer welfare implications from price reactions as the differential impact depends on the relative importance of process and quality adjustments.[38] We highlight this feature in Panels (c) and (d) of Figure 3 by relating the welfare effects across sectors to horizontal and vertical product differentiation. Higher horizontal differentiation (a lower elasticity of substitution σ) implies that consumers care more about product variety resulting in a stronger direct welfare loss. As a consequence, Panel (c) shows a positive relation between horizontal differentiation and welfare losses of credit frictions. The role of horizontal differentiation for welfare is especially important in sectors with low scope for vertical product differentiation belonging to region I in Figure 2. Within this category, sectors with low horizontal differentiation (marked by triangles in panels (c) and (d) of Figure 3) show relatively smaller welfare changes, while sectors with high horizontal differentiation (marked with circles) react with stronger welfare losses to credit frictions. In contrast, for sectors in region III of Figure 2, welfare effects are reduced with increasing scope for vertical product differentiation (marked by squares in panels (c) and (d) of Figure 3.) This result is driven by the fact that direct welfare losses become larger when quality innovations are subject to more convex investment costs (higher α). Conversely, a larger scope for quality reduces the losses in product variety arising from credit frictions.[39]

The counterfactual analysis highlights that the relationship between productivity, prices and welfare becomes more complicated than suggested by models that capture either cost-based or quality-based sorting. Hence, inferring welfare implications of financial shocks from the reaction of prices and productivity based on these models leads to inaccurate conclusions about the underlying mechanism if general equilibrium adjustments of innovations are not taken into account. These distortions of prices and productivity measures arising from the interaction of endogenous innovations and firm exit are not taken into account in existing studies. In particular, Hsieh and Klenow (2009) identify resource misallocation across manufacturing firms and analyze the difference between TFPQ and TFPR. By assuming a constant returns to scale technology and neglecting firm entry, the authors exploit that TFPR is constant across firms without frictions, but capital and output distortions increase prices and TFPR. Instead, Midrigan and Xu (2014) highlight that only a small part of TFP losses can be attributed to misallocation due to financial frictions as suggested by Hsieh

[38] Considering all sectors in the model variant without innovations (Panel A in Table 2), the correlation between price reponses and welfare effects is 0.773. Excluding the sectors Transport Section (60) and IT (72), which represent outliers due to very low welfare losses, leads to a correlation coefficient of 0.922. Both correlations are highly significant at the 1% level. For the three model variants with endogenous innovations (Panels B - D), the correlations between price and welfare reactions are insignificant and small in magnitude or even close to zero.

[39] Figure B1 in the Appendix shows that these patterns qualitatively hold in a model with only quality innovations when the ratio of quality innovations to sales is used as a measure for vertical product differentiation.

and Klenow (2009). In line with evidence of Buera et al. (2011), the authors emphasize the important role of the extensive margin and the interaction of financial frictions with entry barriers in order to explain productivity differences across countries and sectors. Related to this, we allow for fixed costs and endogenous entry, which leads to additional distortions of prices and productivity measures. Our results suggests that accounting for the importance of process and quality innovations measured by the investment intensity relative to sales is key to determine the effects of credit frictions across sectors (see Figure 3). Building on a trade model where firms differ both in productivity and distortions, Berthou et al. (2020) show that resource misallocation across firms has ambiguous effects on the gains from trade. While we focus on the effects of credit frictions, the authors find that export and import shocks lead both to aggregate productivity gains, but have differential implications for resource allocation across firms. Evidence on European data shows that export expansion reallocates activity towards more productive firms, especially when market distortions are relevant. This relates to our model where credit frictions distort the entry of low productivity firms and increase market shares of larger producers through higher innovation activity.[40]

Robustness checks. We conduct several robustness checks to evaluate the impact of exogenous parameters on our quantitative results. While we discuss the main differences to the baseline quantification, the results of all robustness checks are reported in the Online Appendix. With respect to the first step of the calibration procedure, we consider not only labor costs but also include annual expenditure on electricity. Compared to the baseline results in Table 1, this implies slightly larger estimates for the elasticity of substitution σ across sectors. While this increases the values for the investment cost parameters α and β, it does not change the scope for vertical product differentiation in Equation (15). Hence, in comparison to Panel D of Table 2, the direction of price and productivity reactions is unchanged. The magnitude of the effects is slightly smaller as the investment cost functions become more convex, which reduces adjustments of innovations, prices and welfare.

We additionally consider a lower elasticity of marginal production costs with respect to quality ($\theta = 0.75$). Ceteris paribus, this leads to a positive price effect following Equation (A8). However, note that we target the scope for vertical product differentiation (15), such that a decrease in θ leads to a larger estimate for α to ensure that the relative importance of quality innovations and process innovations is unchanged. These counteracting effects

[40]Berthou et al. (2020) allow for heterogeneity in productivity and distortions that are both firm-specific and drawn from a joint distribution without considering endogenous innovations. Our setting is based on firms that differ in their capabilities to invest in processes and quality, and introduces credit frictions that represent an entry barrier for the least productive firms. More generally, one common feature is that distortions drive a wedge between the cutoff level of the least efficient firms and measures of productivity and welfare. Related, Foellmi et al. (2021) provide theory and evidence that credit constraints reduce welfare gains from trade by reducing R&D investments of firms.

explain why price reactions tend to be more negative which increases TFPQ, while the responses of welfare and TFPR remain unchanged compared to Table 2.

In the baseline specification, we have assumed that the Pareto shape parameter is the same for all sectors. We use estimates from Crozet and Koenig (2010) to allow for differences in the productivity distribution across industries. Note that this does not affect the values for the elasticity of substitution, and the investment cost parameters. Sectors with a larger Pareto shape parameter face slightly stronger welfare losses, while the main implications remain unchanged. A more skewed productivity distribution leads to stronger selection effects and hence larger losses in product variety from credit frictions.

We further show that our results are robust to alternative values of variable trade costs.[41] Note that this does not change the parameter values obtained from the first two estimation steps. However, relative fixed exports costs have to increase compared to Table 1 in order to match the share of exporters (25). As the effects of credit frictions depend on the joint size of variable and fixed trade costs, the differences compared to Table 2 are negligibly small.

In the last step, we have used private credit to GDP as a country-level proxy for financial development. Alternatively, we allow for variation in the access to external finance across sectors. The World Bank Enterprise Surveys ask firms to report the shares of working capital, and of investments that were financed by internal sources, such as retained earnings, and external funds, including bank credit. We compute the sum of total production costs (net of labor costs) and investments that is financed by external sources and divide the amount by firm sales. Using the mean value by sector provides a direct proxy for the theoretical counterpart in Equation (19). Sectors with larger credit amount relative to sales have better access to finance, reflected by lower values of the private benefit b.[42] Welfare losses tend to be larger in sectors with higher levels of credit frictions without changing the main implications compared to the baseline specification.

Finally, we quantify the model for Peru in 2016, and Mexico in 2010. For both countries, financial development is lower and hence welfare losses of credit frictions are larger compared to Table 2.[43] Similar to Colombia, the average price response to credit frictions is negative for Peru, which results in a larger (positive) TFPQ reaction compared to TFPR. In contrast, prices increase in response to credit frictions on average across Mexican sectors leading to a smaller reaction of TFPQ.

[41] In the Online Appendix, we show results for variable trade costs $\tau = 1.3$ instead of 1.7.

[42] Note that both variants allow to obtain sector-specific values for the private benefit b, as the relationship in Equation (19) depends on investment cost parameters and export costs from the previous estimation steps. The alternative variant additionally allows for variation in the amount of credit relative to sales across sectors.

[43] The ratio of credit for GDP is 0.2265 for Mexico in 2009, and 0.4281 for Peru in 2016, which translates into larger values for the private benefit across sectors compared to the baseline estimation for Colombia.

6 Conclusion

This paper analyzes the effects of credit frictions on prices, productivity measures and welfare in a model with two sources of firm heterogeneity. Producers differ in capabilities to conduct process innovations and quality innovations, where investment costs have to be financed by external credit. Process innovations decrease marginal production costs and hence prices, whereas quality innovations shift demand outward but increase prices. Compared to existing models, our framework with cost-based and quality-based sorting shows that inferring welfare implications from price effects leads to inaccurate conclusions if general equilibrium adjustments of innovations are not taken into account. Stronger credit frictions lead to firm exit, increasing innovation activity of remaining firms due to decreased competition. If the scope for vertical product differentiation is large, positive price effects attenuate the response of quantity-based average productivity (TFPQ) compared to revenue-based productivity (TFPR). In a counterfactual analysis, we show that these differential effects are quantitatively important compared to existing classes of models that capture either only one dimension of innovations or no innovations. We highlight that welfare effects can be inferred from price reactions after adjusting for the relative importance of process and quality innovations. Hence, our analysis contributes to an influential literature that analyzes price variation across firms and countries to infer the determinants of export performance and associated welfare effects.

Our results have also important implications for studies that estimate productivity effects and identify the determinants of firm-level performance. Distinguishing cost-based and quality-based channels is highly relevant for the design of effective public policies that aim to reduce distortions of credit frictions. Our framework suggests that the relative importance of cost-based and quality-based effects interacts with credit frictions, which shapes pricing patterns and productivity adjustments across firms and sectors.

Our analysis could be further developed in several directions. First, taking into account endogenous markups is important for the estimation of firm-level productivity. Second, we assume one type of external finance for the sake of tractability, whereas selection of firms into different types of credit affects the design of optimal policies. Third, relaxing the assumption of symmetric countries could generate additional insights how bilateral differences in financial development affect export margins. Fourth, while we focus on differences in firms' capability to innovate, the model could be extended by heterogeneity in export entry costs. Finally, we rely on a static framework, whereas dynamic effects of financing and innovation choices play an important role for firm performance. Analyzing differentials effects of quality and process innovations on firm dynamics is a promising avenue for future research.

A Theoretical results

A.1 Marginal-access condition and selection pattern of firms

Inserting effective marginal production costs (10) and sales (12) into the marginal-access condition (16) leads to an explicit solution for the cutoff level of combined capability that is necessary to obtain external finance:

$$z_j = \left(\frac{r}{\lambda}\right)^{\alpha+\beta(1-\theta)} \beta^{\alpha} \left(\frac{\alpha}{1-\theta}\right)^{\beta(1-\theta)} A_j^{\frac{-\alpha\beta}{\sigma-1}} \left(\frac{\alpha\beta\,(\sigma-1)}{\gamma}\frac{r+b}{\lambda} f_j\right)^{\frac{\gamma}{\sigma-1}}. \tag{A1}$$

Comparing the cutoff levels for exporters and non-exporters leads to the following condition: $z_l > z_h$ if $\frac{f_l}{f_h}\left(1+\tau^{1-\sigma}\right)^{\frac{-\alpha\beta}{\gamma}} > 1$. If this condition holds, the most efficient firms with $z \geq z_l$ export. Firms in the middle range of the (combined) capability distribution ($z_h \leq z < z_l$) sell only domestically, while the least efficient firms ($z < z_h$) have no access to external finance and exit.

A.2 Proofs of propositions

Proof of Proposition 1. The number of firms is given by $M = \frac{\gamma}{\alpha\beta\sigma}\frac{(\lambda+r)L}{\Omega(r+b)\Delta_z f_h}$, where $\Omega \equiv \frac{\xi\gamma}{\xi\gamma-\beta(1-\theta)(\sigma-1)}$, and $\Delta_z \equiv 1+\psi_l\frac{f_l}{f_h}\frac{\left(1+\tau^{1-\sigma}\right)^{\frac{\alpha\beta}{\gamma}}-1}{\left(1+\tau^{1-\sigma}\right)^{\frac{\alpha\beta}{\gamma}}}$ (see the Online Appendix for a detailed derivation). Deriving this equation with respect to the private benefit b and the borrowing rate r leads to:

$$\frac{d\ln M}{d\ln b} = -\frac{b}{r+b} < 0, \frac{d\ln M}{d\ln r} = -\frac{r}{r+b} < 0.$$

Using the free entry condition (17), the derivatives of the cutoff level of combined capability z_h are given by (see the Online Appendix for technical details):

$$\frac{d\ln z_h}{d\ln b} = \frac{\beta(1-\theta)}{\xi}\frac{\Omega b f_h \Delta_z}{E\left[\pi\right]} > 0, \frac{d\ln z_h}{d\ln r} = \frac{\beta(1-\theta)}{\xi}\frac{\Omega r f_h \Delta_z - r\widetilde{f}}{E\left[\pi\right]} > 0. \tag{A2}$$

To derive the general equilibrium effects of credit frictions on innnovation choices, we use the sales function (12), solve the cutoff condition (16) for A_j and insert into Equations (7) and (8):

$$e_j = \left(\frac{r}{\lambda}\right)^{\frac{-1}{\beta}} \beta^{-\frac{1}{\beta}} \left(\frac{(r+b)\,f_j}{\lambda\upsilon}\right)^{\frac{1}{\beta}} z_j^{\frac{1-\sigma}{\beta\gamma}} \varphi^{\frac{\alpha+(1-\theta)(1-\sigma)}{\gamma}} \kappa^{\frac{(\sigma-1)(1-\theta)}{\gamma}}, \tag{A3}$$

$$q_j = \left(\frac{r}{\lambda}\right)^{\frac{-1}{\alpha}} \left(\frac{\alpha}{1-\theta}\right)^{\frac{-1}{\alpha}} \left(\frac{(r+b)\,f_j}{\lambda\upsilon}\right)^{\frac{1}{\alpha}} z_j^{\frac{1-\sigma}{\alpha\gamma}} \kappa^{\frac{\beta+1-\sigma}{\gamma}} \varphi^{\frac{\sigma-1}{\gamma}}, \tag{A4}$$

where $\upsilon \equiv \frac{1}{\sigma-1} - \frac{1}{\beta} - \frac{1-\theta}{\alpha} > 0$. Taking the derivatives with respect to b and using that $\frac{d\ln(\lambda\widetilde{s})}{d\ln b} = \frac{b}{r+b}$, leads to:

$$\frac{d\ln e_j}{d\ln b} = \frac{1}{\beta}\frac{d\ln(\lambda\widetilde{s})}{d\ln b} - \frac{\sigma-1}{\beta\gamma}\frac{d\ln z_h}{d\ln b} > 0; \frac{d\ln q_j}{d\ln b} = \frac{1}{\alpha}\frac{d\ln(\lambda\widetilde{s})}{d\ln b} - \frac{\sigma-1}{\alpha\gamma}\frac{d\ln z_h}{d\ln b} > 0. \tag{A5}$$

By inserting the derivative of the cutoff level (A2), we obtain:

$$\frac{d\ln e_j}{d\ln b} = \frac{1}{\beta}\frac{b}{r+b}\left(1 - \frac{\beta(\sigma-1)(1-\theta)}{\xi\gamma}\frac{E[\pi]+r\widetilde{f}}{E[\pi]}\right), \tag{A6}$$

$$\frac{d\ln q_j}{d\ln b} = \frac{1}{\alpha}\frac{b}{r+b}\left(1 - \frac{\beta(\sigma-1)(1-\theta)}{\xi\gamma}\frac{E[\pi]+r\widetilde{f}}{E[\pi]}\right). \tag{A7}$$

The investment responses are positive as long as $\frac{\beta(1-\theta)(\sigma-1)}{\xi\gamma}\frac{E[\pi]+r\tilde{f}}{E[\pi]} < 1$. Note that $\frac{\beta(1-\theta)(\sigma-1)}{\xi\gamma} < 1$ (see Condition 1), and $\frac{\partial\left(\frac{E[\pi]+r\tilde{f}}{E[\pi]}\right)}{\partial b} < 0$. Hence, the derivatives in Equations (A6) and (A7) are positive whenever the private benefit is sufficiently high. The derivatives of the optimal price in Equation (11) can be derived analogously:

$$\frac{d\ln p_j}{d\ln b} = \frac{\beta\theta-\alpha}{\alpha\beta}\underbrace{\left(\frac{b}{r+b} + \frac{1-\sigma}{\gamma}\frac{d\ln z_j}{d\ln b}\right)}_{>0}. \tag{A8}$$

Proof of Proposition 2. Welfare equals real income per consumer and can be written as a function of the quality-adjusted price index (see section 2.1):

$$X = IP^{-1} = \left(\frac{\sigma-1}{\sigma}I\right)^{\frac{\sigma}{\sigma-1}}\beta^{-\frac{1}{\beta}}\left(\frac{1-\theta}{\alpha}\right)^{\frac{1-\theta}{\alpha}} r^{-\frac{\alpha+\beta(1-\theta)}{\alpha\beta}}\left(\frac{\upsilon}{(r+b)f_d}\right)^{\frac{\gamma}{\alpha\beta(\sigma-1)}} z_h^{\frac{1}{\alpha\beta}}, \tag{A9}$$

where $I = (\lambda + r)L$. We provide more technical details on the derivation of welfare in the Online Appendix. The elasticity of welfare (A9) with respect to credit frictions is given by:

$$\frac{d\ln X}{d\ln b} = -\frac{1}{\alpha\beta}\left(\frac{\gamma}{\sigma-1}\frac{b}{r+b} - \underbrace{\frac{d\ln z_h}{d\ln b}}_{>0}\right) < 0. \tag{A10}$$

We insert the reaction of the cutoff level (A2) into Equation (A10), which leads to:

$$\frac{d\ln X}{d\ln b} = -\frac{\gamma}{\alpha\beta(\sigma-1)}\frac{b}{r+b}\left(1 - \frac{\beta(1-\theta)(\sigma-1)}{\xi\gamma}\frac{E[\pi]+r\tilde{f}}{E[\pi]}\right). \tag{A11}$$

The reaction of welfare is negative whenever $\frac{\beta(1-\theta)(\sigma-1)}{\xi\gamma}\frac{E[\pi]+r\tilde{f}}{E[\pi]} < 1$, which is exactly the condition derived in the proof of Proposition 1. An increase in the interest rate r leads to the following welfare effect:

$$\frac{d\ln X}{d\ln r} = -\frac{1}{\sigma-1} - \frac{1}{\alpha\beta}\left(\frac{\gamma}{\sigma-1}\frac{b}{r+b} - \underbrace{\frac{d\ln z_h}{d\ln r}}_{>0}\right).$$

By taking into account the effect of the borrowing rate on the cutoff level z_h in Equation (A2), we can rewrite the welfare response:

$$\frac{d\ln X}{d\ln r} = -\frac{\alpha+\beta(1-\theta)}{\alpha\beta} - \frac{\gamma}{\alpha\beta(\sigma-1)}\frac{r}{r+b} + \frac{1-\theta}{\alpha\xi}\frac{\Omega r f_d \Delta_z - r\widetilde{f}}{E[\pi]}, \tag{A12}$$

where the first term on the RHS captures the intensive margin effect. The second and third terms show the extensive margin effect, which is negative if:

$$\frac{\xi\gamma}{\beta(\sigma-1)(1-\theta)} > \frac{\Omega(r+b) f_d \Delta_z - (r+b)\widetilde{f}}{\Omega(r+b) f_d \Delta_z - r\widetilde{f}}.$$

Note that the LHS is larger than one under Condition 2, and the RHS is smaller than one. Thus, both adjustments at the intensive and extensive margin lead to negative welfare effects.

Proof of Proposition 3. We combine Equations (A8) and (24) to obtain the effect of credit frictions on quantity-based productivity (TFPQ):

$$\frac{d\ln\tilde{\Phi}_j^Q}{d\ln b} = \frac{r f_j}{\lambda\tilde{l}_j + r\tilde{d}_j}\frac{b}{r+b} - \frac{\beta\theta-\alpha}{\alpha\beta}\left(\frac{b}{r+b} - \frac{\sigma-1}{\gamma}\frac{d\ln z_j}{d\ln b}\right). \tag{A13}$$

By neglecting the last effect of credit frictions on the cutoff level z_j in Equation (A13), a necessary condition for $\frac{d\ln\tilde{\Phi}_j^Q}{d\ln b} < 0$ is that $\frac{\beta\theta-\alpha}{\alpha\beta} > \frac{r f_j}{\lambda\tilde{l}_j + r\tilde{d}_j}$, which can be written as follows:

$$\frac{\beta\theta-\alpha}{\alpha\beta} > \frac{1}{\frac{\Omega(r+b)}{rv}\left(1+\frac{1}{\beta}+\frac{1-\theta}{\alpha}\right)+1}. \tag{A14}$$

Note that the left-hand side of this condition decreases in α, whereas the right-hand side term increases in α, such that the condition is satisfied for sufficiently low values of α relative to β. If we take into account the effect of credit frictions on z_j, as shown in Equation (A2), a sufficient condition for a negative effect on TFPQ can be written as:

$$\frac{\beta\theta-\alpha}{\alpha\beta}\left(1-\frac{\beta(1-\theta)\left(\sigma-1\right)}{\xi\gamma}\frac{E\left[\pi\right]+r\tilde{f}}{E\left[\pi\right]}\right)>\frac{1}{\frac{\Omega(r+b)}{rv}\left(1+\frac{1}{\beta}+\frac{1-\theta}{\alpha}\right)+1}. \tag{A15}$$

From the proof of Proposition 1 follows that $\frac{\beta(1-\theta)(\sigma-1)}{\xi\gamma}\frac{E[\pi]+r\tilde{f}}{E[\pi]}<1$. Hence, the relative size of α compared to β is still decisive to determine the direction of the effect. However, the left-hand side becomes smaller compared to Equation (A14), such that lower values of α are required to meet the sufficient condition in Equation (A15).

A.3 Effect of interest rate on firm-level outcomes

Analogous to the case of stronger credit frictions in Proposition 1, a higher borrowing rate leads to a reduction in product variety and increases the cutoff level of combined capability: $\frac{d\ln M}{d\ln r}=-\frac{d\ln(\lambda\tilde{s})}{d\ln r}=-\frac{r}{r+b}<0$, $\frac{d\ln z_h}{d\ln r}>0$. The impact of credit costs on innovations is:

$$\frac{d\ln e_j}{d\ln r}=-\frac{1}{\beta}\left(\frac{b}{r+b}+\frac{\sigma-1}{\gamma}\frac{d\ln z_j}{d\ln r}\right)<0;\frac{d\ln q_j}{d\ln r}=-\frac{1}{\alpha}\left(\frac{b}{r+b}+\frac{\sigma-1}{\gamma}\frac{d\ln z_j}{d\ln r}\right)<0. \tag{A16}$$

To obtain Equation (A16), we take the derivatives of Equations (A3) and (A4) with respect to the borrowing rate r. We take into account the change in the cutoff level as shown in Equation (A2), which leads to:

$$\frac{d\ln e_j}{d\ln r}=-\frac{1}{\beta}\left(\frac{b}{r+b}+\frac{\sigma-1}{\gamma}\frac{\beta(1-\theta)}{\xi}\frac{\Omega rf_d\Delta_z-r\widetilde{f}}{\Omega\left(r+b\right)f_d\Delta_z-r\widetilde{f}}\right)<0. \tag{A17}$$

The changes of all other firm-level variables can be derived analogously. Hence, the impact of credit costs on price setting follows from Equation (11):

$$\frac{d\ln p_j}{d\ln r}=\frac{\alpha-\beta\theta}{\alpha\beta}\left(\frac{b}{r+b}+\frac{\sigma-1}{\gamma}\frac{d\ln z_j}{d\ln r}\right). \tag{A18}$$

Analogous to changes in credit frictions, the effect of credit costs on TFPQ can be decomposed in the reaction of TFPR and the change in prices:

$$\frac{d\ln\tilde{\Phi}_j^Q}{d\ln r}=\underbrace{\frac{d\ln\tilde{\Phi}_j^R}{d\ln r}}_{<0}-\frac{d\ln\tilde{p}_j}{d\ln r}\lesseqgtr 0. \tag{A19}$$

where the effect of credit costs on TFPR is always negative, $\frac{d\ln\tilde{\Phi}_j^R}{d\ln r} = -\frac{rf_j}{\lambda\tilde{l}_j + r\tilde{d}_j}\frac{b}{r+b} < 0$, and the reaction of prices depends on the scope for vertical product differentation according to Equation (A18).

A.4 Comparison of results in partial and general equilibrium

	Partial equilibrium				**General equilibrium**			
Financial shock	$r\uparrow$		$b\uparrow$		$r\uparrow$		$b\uparrow$	
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 3: Firm-level effects of financial shocks in partial and general equilibrium
* indicates that the general equilibrium effect has the same sign, but is quantitatively smaller than the response in partial equilibrium. A high degree of vertical differentiation is present if $\alpha < \beta\theta$.

B Results of counterfactual analysis

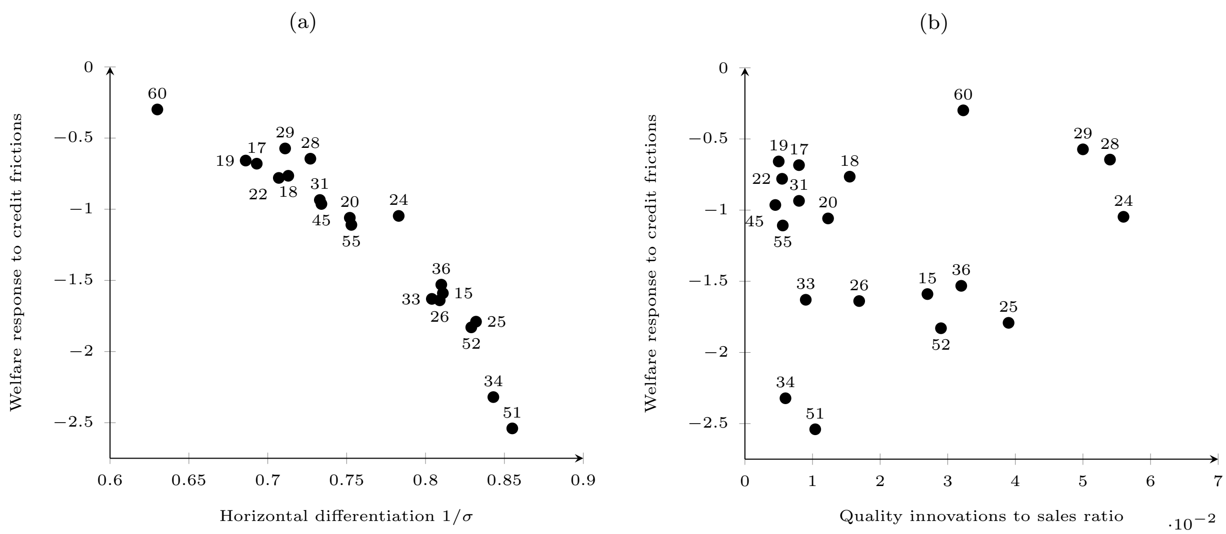


Figure B1: Relation of welfare response to credit frictions with (a) horizontal differentiation and (b) quality differentiation in model with only quality innovations.

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