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

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June 7, 2021

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 effectively conduct process and quality innovations, where external finance is needed for investment outlays. Stronger credit frictions lead to firm exit, higher innovation activity of surviving producers, and opposing effects on prices depending on 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.

JEL Classification: F12, G32, L11

Keywords: international trade, external finance, credit constraints, quality, innovation, product prices, productivity, welfare effects.

*We are grateful to Daniel Baumgarten, Peter Egger, Gabriel Felbermayr, Lisandra Flach, Anna Gumpert, Kalina Manova, Andreas Moxnes, Peter Neary, Banu Demir Pakel, Monika Schnitzer and Erdal Yalcin, as well as participations of the 7th FIW-Research Conference "International Economics" in Vienna, 16th Annual Conference of the European Trade Study Group (ETSG) in Munich, Mainz Workshop in Trade and Macroeconomics, and the 16th Goettingen Workshop International Economics for helpful comments and suggestions. Financial support from the Deutsche Forschungsgemeinschaft through the Collaborative Research Center TRR 190 is gratefully acknowledged.

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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, such as improvements in technological know-how or production methods, that increase a firm's productivity. As a second type we consider quality innovations allowing 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, Fally, and Scarpetta (2007), Beck, Demirgüç-Kunt, and Maksimovic (2008) for evidence on firm size and credit frictions; Paunov (2012) and Archibugi, Filippetti, and Frenz (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. 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 shows that the relation between credit frictions, prices and welfare becomes more complicated than suggested by existing models that typically focus on partial equilibrium and consider only one dimension of adjustment, either quality-based or cost-based sorting. 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. One key result is that the welfare effect of credit frictions can be obtained after adjusting the price response by a correction term that depends on the scope for vertical product differentiation. If the latter is large, the positive price effect does not reflect welfare losses from credit frictions, which requires a negative correction term.

These results have important implications for the interpretation of empirical studies that consider productivity effects and typically focus on revenue-based measures (e.g. Forlani, Martin, Mion, and Muûls, 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). Additionally, 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.

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

To evaluate the importance of the interaction between credit frictions and endogenous innovations, 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. We further highlight that accounting for endogenous adjustments of innovations increases 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 leads to adjustments on the extensive margin.[3] The combination of firm heterogeneity à la Melitz (2003) and financial frictions has received increased attention in international trade models (Manova, 2013; Feenstra, Li, and Yu, 2014; Chaney, 2016), as it provides an explanation for negative effects of credit constraints on firm-level exports and the probability of exporting (Berman and Héricourt, 2010; Minetti and Zhu, 2011; Muûls,

[3]The important role of extensive margin effects for the relationship between financial development and TFP has been highlighted by Buera, Kaboski, and Shin (2011) and Midrigan and Xu (2014), among others.

2015). If firms have to finance fixed export costs, 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. These models imply a negative relationship between firm size and prices (Roberts and Supina, 1996; Foster, Haltiwanger, and Syverson, 2008), and do not capture that innovation choices and prices react endogenously to financial shocks.

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, Head, and Mayer, 2012).[4] Recent work in this strand shows that credit constraints and leverage negatively affect exporters' choice of product quality (Fan, Lai, and Li, 2015; Bernini, Guillou, and Bellone, 2015; Crinò and Ogliari, 2017; Ciani and Bartoli, 2020). In contrast to models based on cost sorting, credit costs decrease export prices because reduced quality levels translate into lower marginal production costs.[5] 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).

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. 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), as well as innovation and productivity development (Midrigan and Xu, 2014). 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.

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, Redding, and Weinstein, 2016; Aw and Lee, 2017;

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

[5]In contrast, Secchi, Tamagni, and Tomasi (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.

Roberts, Yi Xu, Fan, and Zhang, 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.[6] 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.

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

To analyze the impact of credit conditions on innovation and optimal price setting, 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

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

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

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

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

[6]Our model features constant markups, whereas Altomonte, Favoino, Morlacco, and Sonno (2021) show that firm-level heterogeneity in credit frictions explains part of the dispersion of prices and markups.

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

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

By introducing a quality component in the utility function (1), we follow the quality and trade literature.[7] 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.

2.2 Optimal firm behavior

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:

$$C_q(\kappa, q_j) = \frac{q_j^{\alpha}}{\kappa};\ C_e(\varphi, e_j) = \frac{e_j^{\beta}}{\varphi}, \tag{4}$$

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 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 Eq. (4) can be interpreted as production functions for quality and processes, where $\frac{1}{\alpha}$ and $\frac{1}{\beta}$ reflect the

[7] See e.g. Baldwin and Harrigan (2011), Kugler and Verhoogen (2012), and Hallak and Sivadasan (2013).

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:

$$mc(e_j, q_j) = \frac{q_j^{\theta}}{e_j} \text{ , with } 0 < \theta < 1. \tag{5}$$

The benefit of process innovations e_j is a reduction of marginal production costs. Quality innovations q_j increase demand for one variety (3), 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 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 (4).

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]

[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).

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

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 for external credit d_j is given by the following constraint:

$$d_j \geq f_j + \frac{q_j^\alpha}{\kappa} + \frac{e_j^\beta}{\varphi}. \tag{6}$$

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:

$$\lambda k_j \geq r d_j, \tag{7}$$

[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.

[12] See the discussion in Section 3. In Appendix B.3, 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.

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 and Appendix B.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 (6) and the investor's participation constraint (7) hold with equality.

Depending on their export status $j \in h, l$, firms choose optimal investment levels and prices to maximize expected profits subject to the constraints (6) and (7):

$$\max_{p_j, p_l^*, e_j, q_j} \lambda \pi_j = \lambda \left[p_j x_j + 1_{\{j=l\}} p_l^* x_l^* - mc(q_j, e_j) \left(x_j + 1_{\{j=l\}} \tau x_l^* \right) - k_j \right], \tag{8}$$

where demand is given by Eq. (3) 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 (5) and hence also domestic prices differ across non-exporters and exporters as they have different incentives to innovate. From the firm's maximization problem we derive the optimal choices of process and quality innovations (see Appendix A.1 for a detailed derivation):

$$e_j(\varphi, \kappa) = \left(\frac{\lambda A_j}{r} \right)^{\frac{\alpha}{\gamma}} \left(\frac{1-\theta}{\alpha} \kappa \right)^{\frac{(\sigma-1)(1-\theta)}{\gamma}} \left(\frac{\varphi}{\beta} \right)^{\frac{\alpha+(1-\theta)(1-\sigma)}{\gamma}}, \tag{9}$$

$$q_j(\varphi, \kappa) = \left(\frac{\lambda A_j}{r} \right)^{\frac{\beta}{\gamma}} \left(\frac{1-\theta}{\alpha} \kappa \right)^{\frac{\beta+1-\sigma}{\gamma}} \left(\frac{\varphi}{\beta} \right)^{\frac{\sigma-1}{\gamma}}, \tag{10}$$

whereby $\gamma \equiv \alpha\beta + (1-\sigma)\left[\alpha + (1-\theta)\beta\right]$, and $A_h \equiv XP^\sigma \left(\frac{\sigma-1}{\sigma}\right)^\sigma$, $A_l \equiv (1+\tau^{1-\sigma})A_h$ 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 relationship between innovation and market size.[13] 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.

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

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.[14] As the main implications of our model are related to relative differences in investment cost parameters rather than the combined size, this assumption is not crucial for our results. However, imposing restrictions on the parameter values leads to additional insights on firm behavior. If we 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 $\gamma > 0$. This complementary structure relates to the literature on simultaneous process and product R&D choices and is driven by the fact that both types of innovation increase the price-adjusted quality and hence the success of a firm in the market.[15] Consequently, producers will always engage in both types of innovation. The relative investment in processes compared to quality improvements is given by:

$$\frac{e_j(\varphi,\kappa)}{q_j(\varphi,\kappa)} = \left(\frac{\lambda A_j}{r}\right)^{\frac{\alpha-\beta}{\gamma}} \left(\frac{1-\theta}{\alpha}\kappa\right)^{\frac{(\sigma-1)(2-\theta)-\beta}{\gamma}} \left(\frac{\varphi}{\beta}\right)^{\frac{\alpha+(2-\theta)(1-\sigma)}{\gamma}}. \tag{11}$$

The convexity assumption regarding innovation outlays implies further that investments in process innovations relative to quality upgrades increase in the cost-based capability and decrease in the quality-based capability: $\frac{\partial\left(\frac{e}{q}\right)}{\partial\varphi} > 0$, $\frac{\partial\left(\frac{e}{q}\right)}{\partial\kappa} < 0$. Additionally, the relative investment increases in α and decreases in β as firms react to changes in the relative effectiveness of innovations. A higher sensitivity of marginal production costs with respect to quality (larger θ) reduces the marginal benefit of vertical product differentiation and increases the relative investment in processes.

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 $j \in h, l$:

$$p_j(\varphi,\kappa) = \frac{\sigma}{\sigma-1}\frac{q_j^\theta}{e_j} = \frac{\sigma}{\sigma-1}\left(\frac{r}{\lambda A_j}\right)^{\frac{\alpha-\beta\theta}{\gamma}} \left(\frac{1-\theta}{\alpha}\kappa\right)^{\frac{\beta\theta+1-\sigma}{\gamma}} \left(\frac{\beta}{\varphi}\right)^{\frac{\alpha-\sigma+1}{\gamma}}, \tag{12}$$

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

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

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

two opposing effects of investment behavior. A higher level of process innovations enhances production efficiency, whereas quality innovations increase marginal costs according to Eq. (5). Consequently, the optimal price decreases in the cost-based capability φ, but increases in the quality-based capability κ.[16] 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). By inserting the price (12) into Eq. (3), we obtain the optimal domestic quantity:

$$x_j(\varphi,\kappa) = A_j^{\frac{\alpha+(\alpha-\theta)\beta}{\gamma}} \left(\frac{\lambda}{r}\right)^{\frac{\beta(\sigma-1)+\sigma(\alpha-\beta\theta)}{\gamma}} \left(\frac{1-\theta}{\alpha}\kappa\right)^{\frac{\beta[\sigma(1-\theta)-1]+\sigma-1}{\gamma}} \left(\frac{\varphi}{\beta}\right)^{\frac{\sigma(\alpha-1)+1}{\gamma}}, \tag{13}$$

where the exported quantity is given by $x_l^* = \tau^{-\sigma} x_l$. Note that 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 $z = \varphi^{\alpha}\kappa^{\beta(1-\theta)}$ as a measure that summarizes information about both capability draws.

We denote z as the "combined capability" of a firm.[17] This combined capability determines a firm's effective marginal cost which immediately follows from Eqs. (10) and (12):

$$\frac{q_j^{\theta}}{e_j}\frac{1}{q_j}(z) = \left(\left(\frac{r}{\lambda A_j}\right)^{\alpha+\beta(1-\theta)} \beta^{\alpha} \left(\frac{\alpha}{1-\theta}\right)^{\beta(1-\theta)} \frac{1}{z}\right)^{\frac{1}{\gamma}}, \tag{14}$$

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

$$s_j(z) = p_j(\varphi,\kappa)\, x_j(\varphi,\kappa) + 1_{\{x_l^*>0\}} p_l^*(\varphi,\kappa)\, x_l^*(\varphi,\kappa) = A_j \frac{\sigma}{\sigma-1}\left(\frac{q_j^{\theta}}{e_j}\frac{1}{q_j}(z)\right)^{1-\sigma}. \tag{15}$$

Total sales depend positively on market size captured in A_l, while the borrowing rate r and investment cost parameters α and β have a negative impact. We express total firm profits as a function of expected sales:

$$\lambda\pi_j(z) = \frac{\gamma}{\alpha\beta\sigma}\lambda s_j(z) - r f_j, \tag{16}$$

[16] 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.

[17] 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.

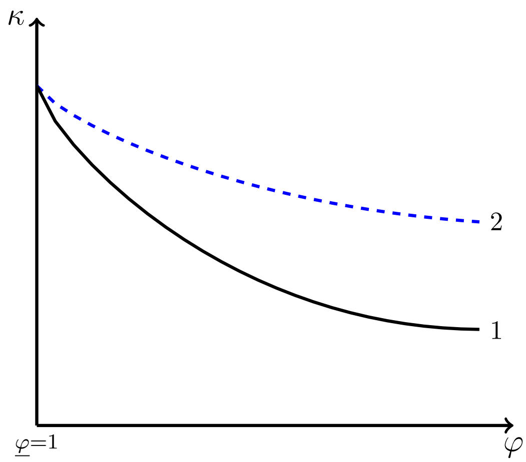


Figure 1: Iso-z curve for low (1) and high (2) vertical differentiation

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 Eqs. (14) - (16) follows that firms with the same z charge the same quality-adjusted price, and earn the same revenues as well as profits. Figure 1 depicts an example for an iso-z curve in the two-dimensional space, where the vertical axis shows the quality-based capability κ and the horizontal axis shows the cost-based capability φ. The curve represents a non-linear trade-off between the two attributes: $\frac{\partial\kappa}{\partial\varphi} < 0$ and $\frac{\partial^2\kappa}{\partial\varphi^2} > 0$. Note that two firms located on the same iso-z curve have the same revenues and 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. To see this, we insert the optimal investment levels in Eqs. (9) and (10) into the investment cost functions (4):

$$\frac{1}{\varphi}e_j^{\beta}(z) = \frac{\sigma-1}{\beta\sigma r}\lambda s_j(z);\; \frac{1}{\kappa}q_j^{\alpha}(z) = \frac{(\sigma-1)(1-\theta)}{\alpha\sigma r}\lambda s_j(z). \tag{17}$$

As investment outlays are a fraction of sales, firms with identical combined capability will spend the same amount on process and quality innovations. Eq. (17) further implies that credit repayment in Eq. (7) can also be expressed in terms of sales: $\lambda k_j = rf_j + \frac{\sigma-1}{\sigma}\lambda s_j(z)\left(\frac{1}{\beta}+\frac{1-\theta}{\alpha}\right)$.[18] 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 Eq. (17), 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:

$$\frac{\frac{1}{\kappa}q_j^{\alpha}(z)}{\frac{1}{\varphi}e_j^{\beta}(z)} = \frac{(1-\theta)\,\beta}{\alpha}. \tag{18}$$

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. The scope for vertical product differentiation in Eq. (18) 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.[19] Examples of sectors with a large scope for quality differentiation are drugs and medicines, cosmetics and precious jewellery; very low degrees of product differentiation are reported for cement, petroleum refineries and builder's carpentry (Kugler and Verhoogen, 2012; Flach and Unger, 2021). 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. 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

[18] See Appendix A1 for a more detailed discussion.

[19] Following Khandelwal (2010), higher consumer's valuation for quality, conditional on prices, translates into larger market volumes and represents a proxy for a market's quality ladder.

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, Desai, and Foley, 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 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 Appendix B.2, we also show that the key insights of our model hold if the private benefit is related to the total credit amount.[20] Note that realized profits and loan repayments are zero in case of shirking.[21] Hence, to rule out losses from lending, the optimal credit contract has to satisfy the following incentive compatibility constraint:

$$\lambda \pi_j \geq bf_j. \tag{19}$$

In order to ensure diligent behavior, the financial sector grants credit only to those firms that have sufficiently high profits. Note that profits in Eq. (16) are a function of the combined capability z. Hence, the binding financial constraint (19) determines a cutoff level of combined capability for (non-)exporters that is necessary to obtain external finance:

$$z_j = \left(\frac{r}{\lambda}\right)^{\alpha+\beta(1-\theta)} \beta^{\alpha} \left(\frac{\alpha}{1-\theta}\right)^{\beta(1-\theta)} A_j^{\frac{-\alpha\beta}{\sigma-1}} \left(\frac{\alpha\beta\,(\sigma-1)}{\gamma}\frac{r+b}{\lambda}f_j\right)^{\frac{\gamma}{\sigma-1}}. \tag{20}$$

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 Eq. (20) 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 $z < z_j$. 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).

Note that Holmstrom and Tirole (1997) consider differences in wealth, whereas in our

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

[21]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.

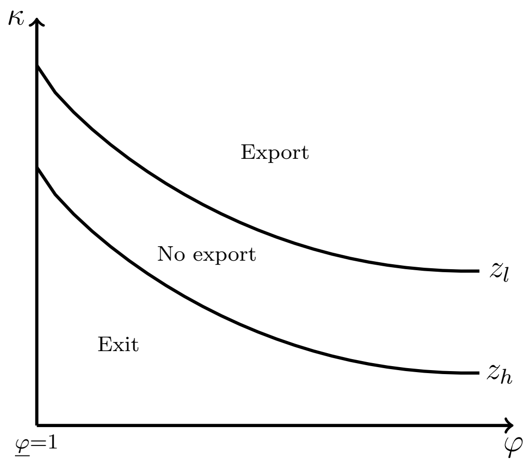


Figure 2: Selection pattern in the open economy

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.

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). If fixed export costs f_l and variable trade costs τ are sufficiently high, only the most capable firms select into exporting:

Condition 1 $z_l > z_h$ *if* $\frac{f_l}{f_h}\left(1+\tau^{1-\sigma}\right)^{\frac{-\alpha\beta}{\gamma}} > 1$.

This condition differs from Melitz (2003) because exporters spread expenditures associated with endogenous investments across sales in both markets.[22]

Proposition 1 *If Condition 1 holds, the most efficient firms with $z \geq z_l$ export. Producers 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.*

Graphically, Eq. (20) specifies the location of a marginal-access curve in the two-dimensional capability space (φ, κ). Figure 2 depicts the selection pattern of firms under Proposition 1, whereby the marginal-access curve for exporting lies above the one for domestic activity.[23] Marginal firms, characterized by the cutoff levels of combined capability z_j, just meet incentive compatibility (19) and are indifferent between diligent behavior and shirking, such that profits are equal to the probability-weighted private benefit: $\pi\left(z_j\right) = \frac{bf_j}{\lambda}$.

[22] In Melitz (2003), a similar condition requires that $\frac{f_l}{f_h}\tau^{\sigma-1} > 1$.

[23] The two-dimensional selection pattern is closely related to Sutton (2007).

Additionally, revenues and investment expenditures of marginal producers are independent of capabilities:

$$s_j(z_j) = \frac{\alpha\beta\sigma}{\gamma\lambda}(r+b)\, f_j, \tag{21}$$

$$\frac{1}{\varphi}e_j^{\beta}(z_j) = \frac{\alpha(\sigma-1)}{\gamma r}(r+b)\, f_j;\ \frac{1}{\kappa}q_j^{\alpha}(z_j) = \frac{\beta(1-\theta)(\sigma-1)}{\gamma r}(r+b)\, f_j. \tag{22}$$

These expressions for marginal firms are obtained by combining optimal innovation choices (9) and (10) with Eq. (20). A larger private benefit b aggravates moral hazard, which increases the minimum cutoff level of the combined capability (20) that is required to meet incentive compatibility (19). This forces low capability firms to exit, corresponding to an upward-shift of marginal-access curves in Figure 2. Similar selection effects occur if fixed production costs go up. Furthermore, the cutoff level (20) increases in technology cost parameters α and β, and decreases in market size A_j.

These selection effects depend on the scope for vertical product differentiation. The slope of the marginal-access curve in the two-dimensional capability space is the negative inverse of Eq. (18): $\frac{d\ln\kappa}{d\ln\varphi} = -\frac{\alpha}{\beta(1-\theta)}$. Hence, sectors with higher quality differentiation are characterized by flatter marginal-access curves (see Figure 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 Eq. (12) follows that the relation of prices and firm size is given by: $\frac{d\ln p_j}{d\ln\varphi} + \frac{d\ln p_j}{d\ln\kappa} = \frac{\beta\theta-\alpha}{\gamma}$. Hence, consistent with empirical evidence, prices and firm size are positively correlated if the scope for vertical product differentiation is high (e.g. Manova and Zhang, 2012). Larger firms with higher quality-based capability κ invest more in quality upgrades resulting in higher prices.

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, we exploit that the combined capability z of a firm determines revenues and profits, as well as the selection into production and exporting. Analogous to single-attribute firm models as in Melitz (2003), this allows us to characterize the equilibrium by two conditions that relate the expected profits in the economy to the combined capability of the marginal entrant z_h. We further use a condition for labor market clearing that relates the endogenous mass of active firms to the cutoff level z_h. Note that all endogenous firm variables, including innovation choices, prices, revenues and profits can be expressed as a function of the marginal capability as well. We first define the three equilibrium conditions to solve for average profits, the cutoff capability z_h, and the mass of active firms. Then we use comparative statics to analyze how financial shocks affect these endogenous variables and hence also firm-level outcomes in general equilibrium.

The first key 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:[24]

$$E\left[\pi\right] = \frac{f_e}{\chi_s}, \tag{23}$$

where $\chi_s = \iint\limits_{(\varphi,\kappa)\in D} g(\varphi,\kappa)d\varphi d\kappa$ is the probability of success and D denotes the set of all active firms in equilibrium as depicted in Figure 2. We abstract from external financing of fixed entry costs, such that expected profits are used to cover entry costs. In Appendix B.3, we show that relaxing this assumption generates additional effects without changing the main implications of our framework.[25]

The second relationship is a marginal-access condition as shown in Eq. (20) that relates the expected profits to the cutoff level for the marginal entrant z_h. Compared to Melitz (2003), note that this relation is not equivalent to a zero-profit condition, as credit frictions prevent access to the market for profitable firms with lowest combined capability. The marginal-access conditions (20) define regions of active firms in the two-dimensional capability space (φ, κ), as shown by Figure 2. Hence, we denote D_j, with $j \in h, l$, as the regions of non-exporters and exporters respectively (see Appendix A.3 for technical details).

To derive this second relationship between profits and the cutoff level z_h, we define average profits as follows:

$$E\left[\pi\right] = \sum_j \psi_j E\left[\pi_j\right] = \sum_j \iint\limits_{(\varphi,\kappa)\in D_j} \lambda \pi_j(\varphi,\kappa)\mu_s(\varphi,\kappa)d\varphi d\kappa, \tag{24}$$

whereby 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 drawing a particular combination of capabilities, conditional on success.

[24]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.

[25]This extension is related to Bonfiglioli, Crinò, and Gancia (2018) who analyze the effect of financial frictions on endogenous firm entry in a heterogeneous firms model of trade.

Analogous to Melitz (2003), revenues of a firm with combined capability z can be expressed relative to the marginal (non-)exporter, characterized by the cutoff level z_j:

$$s_j(z) = \left(\frac{z}{z_j}\right)^{\frac{\sigma-1}{\gamma}} s_j(z_j).$$

As discussed in Section 2.3, revenues of marginal firms depend only on fixed parameters of the model. By using Eq. (21), we write expected revenues and profits by group as follows:

$$\lambda\widetilde{s}_j = \frac{\alpha\beta\sigma}{\gamma}(r+b)\,f_j\left(\frac{\widetilde{z}_j}{z_j}\right)^{\frac{\sigma-1}{\gamma}} ;\; E\left[\pi_j\right] = \frac{\gamma}{\alpha\beta\sigma}\lambda\widetilde{s}_j - rf_j,$$

where the average capability is given by $\widetilde{z}_j^{\frac{\sigma-1}{\gamma}} = \int\int_{(\varphi,\kappa)\in D_j} z^{\frac{\sigma-1}{\gamma}}(\varphi,\kappa)\,\mu_j(\varphi,\kappa)d\varphi d\kappa.$

Combining these expressions with the key relations in Eqs. (23) and (24) determines the minimum level of capability z_h, which just allows firms to be active in the domestic market.

As a third key relation, a factor market clearing condition allows to express the endogenous mass of active firms M as a function of the cutoff level z_h. As labor is used for variable production costs, a firm's labor demand can be written as follows:

$$l_j\left(z\right) = mc_j\left(x_j + 1_{\{j=l\}}\tau x_l^*\right) = \frac{\sigma-1}{\sigma}s_j(z). \tag{25}$$

Eq. (25) shows that firms with higher combined capability z have larger labor requirements as they operate on a bigger scale in terms of sales. In equilibrium, the inelastic labor supply L has to sastify 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:

$$\lambda L = M\left[\left(\frac{\gamma}{\alpha\beta} + \sigma - 1\right)\frac{\lambda\widetilde{s}}{\sigma} - r\widetilde{f}\right], \tag{26}$$

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 (6) 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:

$$K = M\widetilde{d} = M\widetilde{f} + \frac{\alpha\beta-\gamma}{\alpha\beta\sigma r}M\lambda\widetilde{s}. \tag{27}$$

Combining Eqs. (26) and (27) 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. This assumption could be relaxed which generates additional insights about 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 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 Appendix A.3.

Condition 2 $\xi > \frac{\beta(1-\theta)(\sigma-1)}{\gamma}$ *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.[26] This generates a reasonable approximation for the right tail of the observed distribution of firm sizes, as shown by empirical studies (Axtell, 2001; Eaton, Kortum, and Kramarz, 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, Mayer, and Thoenig, 2014).

4 Effects of financial shocks

In this section, we analyze the general equilibrium effects of financial shocks on price setting and welfare. As we consider two symmetric countries, our analysis neglects implications of

[26] Our framework follows a large class of models that feature Pareto distributed firm sizes. See Arkolakis, Costinot, and Rodriguez-Clare (2012) for a discussion of related papers.

bilateral differences in financial development.[27] Two commonly used measures of financial conditions in empirical studies are credit costs and access to external finance (Berman and Héricourt, 2010; Beck, 2013). Accordingly, we analyze the effects of an increase in the borrowing rate r and the impact of aggravated access to credit, captured by 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 in Eq. (19).

Proposition 2 *Stronger credit frictions (higher private benefit b) lead to exit of smallest producers and raise the cutoff level of combined capability z_h: $\frac{d\ln M}{d\ln b} = -\frac{d\ln(\lambda\widetilde{s})}{d\ln b} < 0$ and $\frac{d\ln z_h}{d\ln b} > 0$, as $\frac{d\ln(\lambda\widetilde{s})}{d\ln b} = \frac{b}{r+b} > 0$. An increase in the borrowing rate leads to similar effects: $\frac{d\ln M}{d\ln r} = -\frac{d\ln(\lambda\widetilde{s})}{d\ln r} = -\frac{r}{r+b} < 0$, $\frac{d\ln z_h}{d\ln r} > 0$.*

Proof. See Appendix A.4. ■

The adjustments described in Prop. 2 affect firm-level innovation choices:

$$\frac{d\ln e_j}{d\ln b} = \frac{1}{\beta}\frac{d\ln(\lambda\widetilde{s})}{d\ln b} - \frac{\sigma-1}{\beta\gamma}\frac{d\ln z_h}{d\ln b} > 0; \frac{d\ln q_j}{d\ln b} = \frac{1}{\alpha}\frac{d\ln(\lambda\widetilde{s})}{d\ln b} - \frac{\sigma-1}{\alpha\gamma}\frac{d\ln z_h}{d\ln b} > 0. \quad (28)$$

The first terms of the derivatives in Eq. (28) are positive and capture that a reduction in the number of firms lowers competition, which enhances innovation activity of remaining producers. As the firms with lowest combined capability exit, this positive effect on innovation is counteracted by an increase in the cutoff level z_h. Marginal firms become more capable and hence larger, which reduces benefits of innovation.

Proposition 3 *If Condition 2 is satisfied and the private benefit is sufficiently large, stronger credit frictions (an increase in the private benefit b), reduce competition through exit of firms, and lead to more innovation of existing firms. If the scope for vertical product differentiation in a sector is relatively large ($\alpha < \beta\theta$), stronger credit frictions raise prices.*

Proof. See Appendix A.4. ■

If credit frictions are sufficiently strong, then the negative effect on the number of firms outweighs the positive impact on the cutoff level. Hence, the remaining producers react to lower competition by increasing innovation activities in Eq. (28). The first part of Prop. 3 implies that stronger credit frictions lead to an equilibrium with a lower number of producers

[27] 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.

that are larger on average. The second part of Prop. 3 shows that these adjustments have opposite effects on prices, depending on the scope for vertical product differentiation in Eq. (18). The effect of the private benefit b on price setting is given by:

$$\frac{d\ln p_j}{d\ln b} = \frac{\beta\theta - \alpha}{\alpha\beta} \underbrace{\left(\frac{b}{r+b} + \frac{1-\sigma}{\gamma}\frac{d\ln z_j}{d\ln b}\right)}_{>0}. \tag{29}$$

The condition we impose on the private benefit in Prop. 3 ensures that the term in brackets is positive. Which type of innovation benefits relatively more from lower competition, depends on the scope for vertical product differentiation. Stronger credit frictions increase quality investments relatively more in sectors with high scope for vertical differentiation. This implies that prices react positively in those sectors. Conversely, if the scope for vertical product differentiation is low, surviving firms react to reduced competition by shifting resources towards process innovations, which reduces prices.

In contrast to stronger credit frictions, a higher borrowing rate reduces innovation:

$$\frac{d\ln e_j}{d\ln r} = -\frac{1}{\beta}\left(\frac{b}{r+b} + \frac{\sigma-1}{\gamma}\frac{d\ln z_j}{d\ln r}\right) < 0; \frac{d\ln q_j}{d\ln r} = -\frac{1}{\alpha}\left(\frac{b}{r+b} + \frac{\sigma-1}{\gamma}\frac{d\ln z_j}{d\ln r}\right) < 0. \tag{30}$$

Note that credit costs have a direct negative impact on innovations for all firms. In contrast, aggravated access to finance reduces competition due to exit of firms and hence increases incentives to innovate for remaining producers. Compared to credit frictions, higher borrowing costs also reduce the number of active firms (see Prop. 2). However, this selection effect does not outweigh the direct negative impact of higher borrowing costs. Additionally, there is a rise in the cutoff level, which further reduces innovation activity, as the competitive advantage relative to the marginal firm shrinks.

Reductions in both types of investment influence marginal costs (5) and hence optimal price setting in opposite ways. As Eq. (12) shows, lower process innovations result in higher marginal costs and prices, whereas a decrease in quality innovations leads to the opposite effect. Compared to credit frictions, these negative effects on investments imply a reversed impact of the scope for vertical product differentiation (18) on prices:

$$\frac{d\ln p_j}{d\ln r} = \frac{\alpha - \beta\theta}{\alpha\beta}\left(\frac{b}{r+b} + \frac{\sigma-1}{\gamma}\frac{d\ln z_j}{d\ln r}\right). \tag{31}$$

Proposition 4 *An increase in the borrowing rate reduces innovation of existing firms. If the scope for vertical product differentiation in a sector is relatively high ($\alpha < \beta\theta$), then credit costs reduce prices.*

Proof. See Appendix A.4. ■

Our analysis highlights that inferring the implications of credit frictions from price effects might be misleading, as these effects might be confused with general equilibrium adjustments that vary across sectors depending on the degree of quality differentiation.[28] 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.

Welfare effects. Taking into account general equilibrium adjustments of credit frictions is especially important for the welfare implications of financial shocks. Agents derive utility from the consumption of goods according to Eq. (1) and exert effort by foregoing private benefits. We assume that preferences are separable in consumption and private benefits. Given that incentive compatibility in Eq. (19) is satisfied, there is no consumption of private benefits in equilibrium.[29] Welfare equals real income per consumer and can be written as a function of the quality-adjusted price index (2):

$$X = IP^{-1} = \left(\frac{\sigma-1}{\sigma}I\right)^{\frac{\sigma}{\sigma-1}} \beta^{-\frac{1}{\beta}} \left(\frac{1-\theta}{\alpha}\right)^{\frac{1-\theta}{\alpha}} r^{-\frac{\alpha+\beta(1-\theta)}{\alpha\beta}} \left(\frac{v}{(r+b)\,f_d}\right)^{\frac{\gamma}{\alpha\beta(\sigma-1)}} z_h^{\frac{1}{\alpha\beta}}, \tag{32}$$

where $v = \frac{1}{\sigma-1} - \frac{1}{\beta} - \frac{1-\theta}{\alpha} > 0$, and $I = (\lambda + r)\,L$. We provide more technical details on the derivation of welfare in Appendix A.2. The effects of credit frictions on welfare can be decomposed into two channels:

$$\frac{d\ln X}{d\ln b} = -\frac{1}{\alpha\beta}\left(\frac{\gamma}{\sigma-1}\frac{b}{r+b} - \underbrace{\frac{d\ln z_h}{d\ln b}}_{>0}\right). \tag{33}$$

The first effect in Eq. (33) captures that an increase in credit frictions reduce product variety. As firms with lowest capability exit the market (see Prop. 2), there is a counteracting selection effect leading to an increase in the average price-adjusted quality as reflected by the larger cutoff level z_h.

[28]Table 3 in Appendix B.1 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 Appendix B.2 by allowing for private benefits proportional to total loan size.

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

Proposition 5 *An increase in credit frictions (higher b) reduces welfare through the extensive margin if the private benefit b is sufficiently high. 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.*

Proof. See Appendix A.4. ■

Note that the condition we impose on the private benefit is the same as in Prop. 3. If financial development is low (captured by a high private benefit b), stronger credit frictions will lead to a large reduction in product variety that outweighs efficiency gains. This result is in line with evidence that credit frictions especially hurt smaller firms and restrict market access (Aghion et al., 2007; Beck et al., 2008).[30] We additionally show in Appendix A.4 that an increase in the interest rate leads to similar welfare losses.

As summarized in Prop. 5, one important implication of our model with two types of innovation is that the relation between price reactions and welfare effects of credit frictions becomes more complicated than in existing models with only cost-based or quality-based sorting. To see this, we combine Eqs. (29) and (33), which leads to:

$$\frac{d\ln X}{d\ln b} = -\frac{\gamma}{\sigma-1}\frac{1}{\beta\theta-\alpha}\frac{d\ln p_h}{d\ln b}. \tag{34}$$

This relationship highlights that the welfare effects of credit frictions are a combination of the price effect and a correction term that is determined by the relative size of the investment cost parameters. If the scope for quality differentiation is relatively high ($\alpha < \beta\theta$), then stronger credit frictions raise prices (see Prop. 3). In this case, Eq. (34) requires a negative correction term to obtain the welfare response. If quality differentiation is low ($\alpha > \beta\theta$), credit frictions reduce prices and consequently a positive correction term has to be taken into account to arrive at the true welfare effect. We further investigate the relation between prices and welfare in our counterfactual analysis presented in Section 5.

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:

$$\Phi_j^Q(\varphi,\kappa) = \frac{x_j(\varphi,\kappa)}{l_j(z)+\frac{r}{\lambda}d_j(z)} = \frac{x_j(\varphi,\kappa)}{\frac{\sigma-1}{\sigma}s_j(z)\left(1+\frac{1}{\beta}+\frac{1-\theta}{\alpha}\right)+\frac{r}{\lambda}f_j}, \tag{35}$$

[30]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).

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 Eq. (7). The expression in Eq. (35) 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:

$$\Phi_j^R(z) = \frac{s_j(z)}{l_j(z) + \frac{r}{\lambda} d_j(z)} = \Phi_j^Q(\varphi, \kappa)\, p_j(\varphi, \kappa) = \frac{s_j(z)}{\frac{\sigma-1}{\sigma} s_j(z) \left(1 + \frac{1}{\beta} + \frac{1-\theta}{\alpha}\right) + \frac{r}{\lambda} f_j}. \tag{36}$$

Note that TFPR monotonically increases in a firm's combined capability $z = \varphi^\alpha \kappa^{\beta(1-\theta)}$, which follows immediately from Eq. (36): $\frac{d\Phi_j^R(z)}{dz} = \frac{\frac{r}{\lambda} f_j}{\left[l_j(z) + \frac{r}{\lambda} d_j(z)\right]^2} \frac{ds_j(z)}{dz} > 0$. However, this is not the case for TFPQ. The comparison of Eqs. (35) and (36) 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 Eq. (36) 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 financial shocks across industries. We consider the average levels of the two productivity measures in Eq. (35) and (36):

$$\tilde{\Phi}_j^R = \frac{\frac{\sigma}{\sigma-1}\left(\frac{\tilde{z}_j}{z_j}\right)^{\frac{\sigma-1}{\gamma}}}{\left(\frac{\sigma}{\sigma-1} - \upsilon\right)\left(\frac{\tilde{z}_j}{z_j}\right)^{\frac{\sigma-1}{\gamma}} + \frac{r\upsilon}{r+b}};\ \tilde{\Phi}_j^Q = \frac{\tilde{\Phi}_j^R}{\tilde{p}_j}. \tag{37}$$

Eq. (37) 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 Prop. 2): $\frac{d\ln\tilde{\Phi}_j^R}{d\ln b} = \frac{rf_j}{\lambda\tilde{l}_j + r\tilde{d}_j}\frac{b}{r+b} > 0$, where $\frac{rf_j}{\lambda\tilde{l}_j + r\tilde{d}_j}$ denotes the share of fixed production costs in average costs. Conversely, credit costs reduce investments and hence TFPR: $\frac{d\ln\tilde{\Phi}_j^R}{d\ln r} = -\frac{rf_j}{\lambda\tilde{l}_j + r\tilde{d}_j}\frac{b}{r+b} < 0$.

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:

$$\frac{d\ln\tilde{\Phi}_j^Q}{d\ln b} = \underbrace{\frac{d\ln\tilde{\Phi}_j^R}{d\ln b}}_{>0} - \frac{d\ln\tilde{p}_j}{d\ln b} \lesseqgtr 0. \tag{38}$$

The first term in Eq. (38) captures the increase in TFPR, while the price reaction to credit frictions can go in both directions. If the scope for vertical product differentiation is high, then the average price increases and counteracts the first effect (see Prop. 3).

Proposition 6 *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.*

The proof of Prop. 6 follows immediately from comparing the reaction of TFPR (37) with the price response to credit frictions in Eq. (29). Note that the share of fixed costs in total costs $rf_j/\lambda l_j(z)$ decreases in combined capability z, and hence it becomes more likely for larger firms that TFPR and TFPQ move in opposite directions. Using the expression for average productivity in Eq. (37), we show in Appendix A.4 that the condition stated in Prop. 6 is satisfied for sufficiently low values of α relative to β.

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

$$\frac{d\ln\tilde{\Phi}_j^Q}{d\ln r} = \underbrace{\frac{d\ln\tilde{\Phi}_j^R}{d\ln r}}_{<0} - \frac{d\ln\tilde{p}_j}{d\ln r} \lesseqgtr 0. \tag{39}$$

In contrast to Eq. (38), credit costs reduce TFPR due to lower investments. If the scope for vertical product differentiation is low, higher credit costs reduce process innovations relative to quality investments, which increases firm-level prices. As a consequence, both TFPQ and TFPR decrease. In a sector with high quality differentiation, firms reduce the relative investment in quality, which leads to a price decrease and hence counteracts the negative effect of reduced investments. 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 show that the main implications of our model remain valid if we relax the assumption of a fixed interest rate. We discuss the main insights of this model variant, while providing the technical details in Appendix B.4. We impose that the inelastic capital supply K equals aggregate capital demand in Eq. (27). Substituting for the number of firms in Eq. (26) leads to a capital market clearing condition that implicitly determines the interest rate r:

$$\frac{K}{\lambda L} = \frac{\widetilde{d}}{\lambda\tilde{\pi} + \frac{\sigma-1}{\sigma}\lambda\widetilde{s}} \,, \tag{40}$$

where average profits are defined as $\lambda\tilde{\pi} = \frac{\gamma}{\alpha\beta\sigma}\lambda\widetilde{s} - r\tilde{f}$. In this variant, the analyzed effects of an increase in the interest rate are caused by a reduction in K. With inelastic capital supply, stronger credit frictions lead to an additional effect as they induce a reduction in capital demand and thus lead to a lower 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 Prop. 2). 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 Prop. 3). 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. Overall, we can still show that welfare losses occur if credit frictions are sufficiently strong. Compared to Prop. 5, the condition imposed on the private benefit is more restrictive due to the endogenous adjustment of the interest rate. The productivity effects in Prop. 6 also remain valid as stronger credit frictions reduce borrowing costs which intensifies the positive effect on TFPR beyond the selection effect. As discussed above, the endogenous adjustment of the interest rate also reinforces the reaction of prices to credit frictions without changing the direction of the effects. Hence, the price reaction in Eq. (38) is still determined by the scope for vertical product differentiation (see Appendix B.4 for technical details).

5 Quantitative analysis of credit frictions

To evaluate the importance of the interaction between credit frictions and endogenous innovations, this section quantifies the general equilibrium implications for prices, productivity measures, and welfare. Using data from the World Bank's Enterprise Surveys for Columbia in 2016, we calibrate the model with two types of innovation to match sectoral characteristics related to investment, exporting, and financial development. We 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: (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 use Eq. (25) and 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 Eq. (17) 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 (2021).[31] 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:

$$\psi_l = \left(\frac{f_l}{f_h}\right)^{-\frac{\xi\gamma}{\beta(\sigma-1)(1-\theta)}} \left(1+\tau^{1-\sigma}\right)^{\frac{\alpha\xi}{(\sigma-1)(1-\theta)}}, \tag{41}$$

which allows us to obtain the implied ratio of fixed export costs to domestic fixed costs. As a last step, 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 a proxy for the total credit amount relative to sales in Eq. (27). Together with the estimated parameters from the preceding steps, this allows us to compute sector-specific values for the private benefit b. Table 1 summarizes the targeted moments and the implied parameter values by sector (see Appendix C.1 for technical details of the calibration).

[31] See Appendix C.1 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.

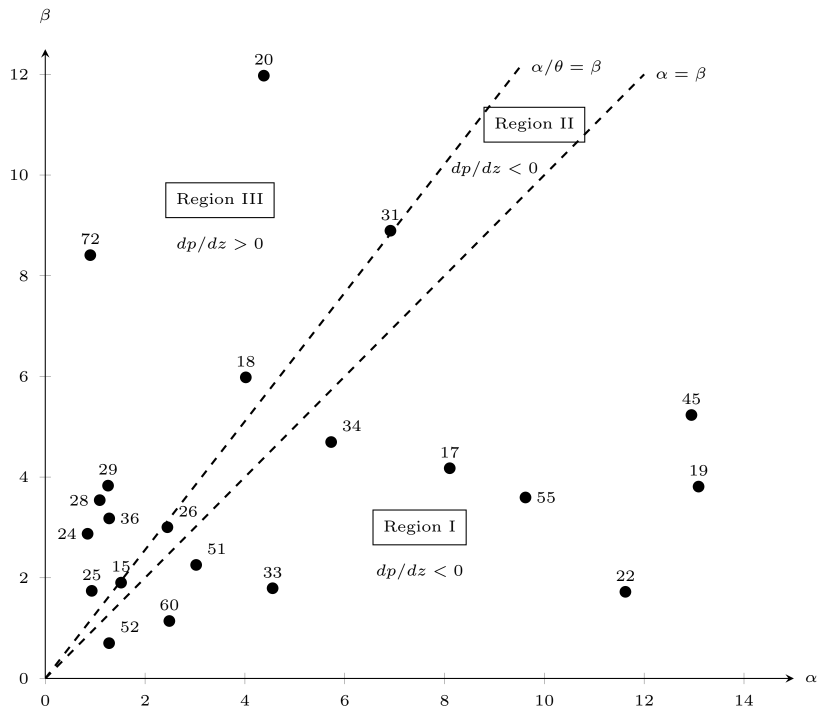
Table 1: Matched moments and parameter estimates by sector

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.

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. Table D1 shows parameter estimates of the benchmark cases; Appendices

C.2-C.4 provide technical details of the counterfactual scenarios.



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 3: 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 ($dp/dz > 0$).

Figure 3 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 Prop. 3). This allows to distinguish three regions depending on the combination of α and β. Figure 3 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 3 summarizes the effects of both financial shocks on endogenous outcomes across regions, as discussed in the previous section. 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 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. Table 2 reports the elasticities of prices (29), welfare (33), and average productivity measures (38) with respect to an increase in credit frictions b. In case of a model without endogenous 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 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 Prop. 3, 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 4 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 Prop. 6). Instead, sectors with limited importance of quality innovations (e.g. leather, textiles) show a stronger reaction of TFPQ (see Panel (b) of Figure 4).

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 two types of innovation (Panel A), only quality innovations (B), only process innovations (C), and for benchmark model without endogenous innovations (D).

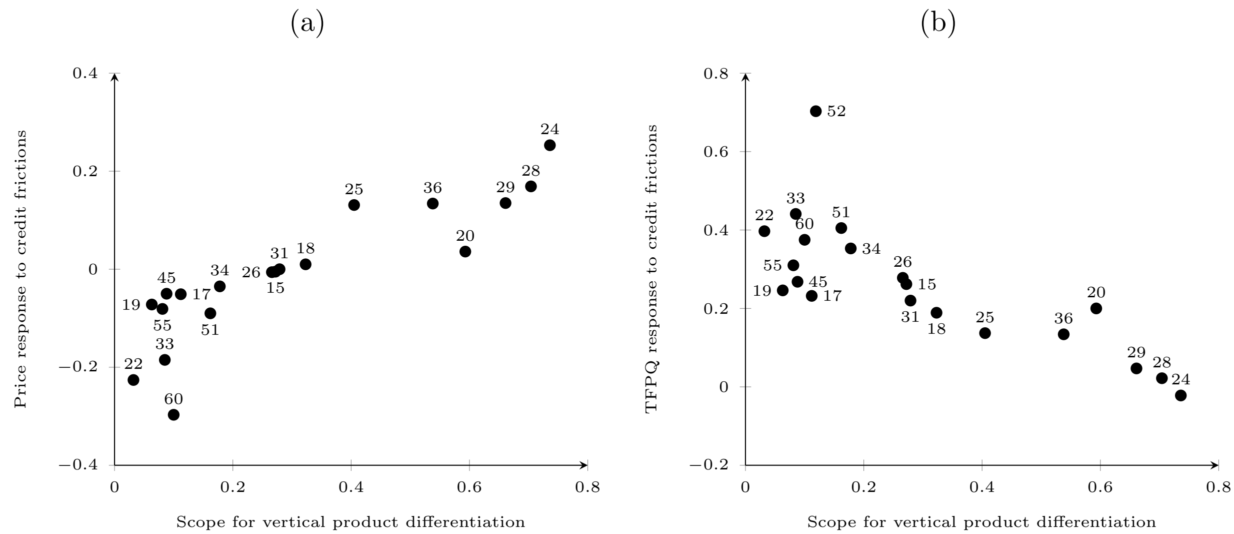


Figure 4: Correlations of scope for vertical product differentiation with price response to credit frictions (panel a), and TFPQ response to credit frictions (b). The correlation coefficients in the two panels are (a) 0.772, and (b) -0.774, which are both significant at the 1% level.

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 Prop. 5). Note that 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 according to Eq. (34) 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. 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).

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 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 4).

Robustness checks. We conduct several robustness checks to evaluate the impact of exogenous parameters on our quantitative results. With respect to the first step of the calibration procedure, we consider not only labor costs but also include annual expenditure on electricity. The average ratios of expenditures for labor and electricity relative to sales by sector are reported in Table D2. Compared to the baseline results in Table 1, the higher expenditure ratios imply 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 Eq. (18). Hence, in comparison to Panel D of Table 2, the direction of price and productivity reactions is unchanged. However, the magnitude of the effects is slightly attenuated as the cost functions of investments become more convex, which reduces adjustments of innovations and prices. Hence, the welfare loss with respect to credit frictions becomes smaller. We show additional results for a lower elasticity of marginal production costs with respect to quality ($\theta = 0.75$) in Table D3 (see Appendix C.1 for details). Ceteris paribus, this leads to a positive price effect following Eq. (29). However, note that we target the scope for vertical product differentiation (18), 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 explain why the price reactions in Table D3 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. Table D4 shows that 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. Table D5 shows results when assuming a lower value for variable trade costs ($\tau = 1.3$ instead of 1.7 above). While the parameters obtained in the first two estimation steps do not change, relative exports costs increase compared to Table 1 in order to match the share of exporters (41). 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 Eq. (27). Sectors with larger credit amount relative to sales have better access to finance, reflected by lower values of the private benefit b (see Table D6).[32] The comparison with Table 2 shows that 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 (see Tables D7 and D8). For both countries, financial development is lower and hence welfare losses of credit frictions are larger compared to Table 2.[33] 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.

[32]Note that both variants allow to obtain sector-specific values for the private benefit b, as the relationship in Eq. (27) 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.

[33]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.

Our results have 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 Appendix

A.1 Maximization problem of firm

This section derives the optimal investment and pricing behavior of a firm with export status $j \in h, l$, where $1_{\{j=l\}}$ takes a value of 1 if the firm is an exporter and is zero otherwise. We insert marginal costs (5) and the demand function (3) into expected profits (8):

$$\lambda\pi_j = \lambda X P^\sigma q_j^{\sigma-1} \left[p_j^{1-\sigma} + 1_{\{j=l\}} \left(p_l^*\right)^{1-\sigma} - \frac{q_j^\theta}{e_j} \left(p_j^{-\sigma} + 1_{\{j=l\}} \tau \left(p_l^*\right)^{-\sigma} \right) \right] - \lambda k_j. \tag{A1}$$

Firms maximize Eq. (A1) subject to the constraints (6) and (7), which are both binding in equilibrium. The first order conditions for optimal domestic prices p_j and export prices p_l^*, as well as investment levels e_j and q_j, are given by:

$$\lambda X P^\sigma q_j^{\sigma-1} \left[(1-\sigma) p_j^{-\sigma} + \sigma p_j^{-\sigma-1} \frac{q_j^\theta}{e_j} \right] = 0, \tag{A2}$$

$$\lambda X P^\sigma q_l^{\sigma-1} \left[(1-\sigma) \left(p_l^*\right)^{-\sigma} + \sigma\tau \left(p_l^*\right)^{-\sigma-1} \frac{q_l^\theta}{e_l} \right] = 0, \tag{A3}$$

$$\lambda X P^\sigma \frac{q_j^{\theta+\sigma-1}}{e_j^2} \left(p_j^{-\sigma} + 1_{\{j=l\}} \tau \left(p_l^*\right)^{-\sigma} \right) - r\frac{\beta}{\varphi} e_j^{\beta-1} = 0, \tag{A4}$$

$$\begin{aligned} &\lambda X P^\sigma (\sigma-1) q_j^{\sigma-2} \left(p_j^{1-\sigma} + 1_{\{j=l\}} \left(p_l^*\right)^{1-\sigma} \right) \\ &+\lambda X P^\sigma \frac{(\theta+\sigma-1) q_j^{\theta+\sigma-2}}{e_j} \left(p_j^{-\sigma} + 1_{\{j=l\}} \tau \left(p_l^*\right)^{-\sigma} \right) - r\frac{\alpha}{\kappa} q_j^{\alpha-1} = 0. \end{aligned} \tag{A5}$$

The optimal prices (12) follow immediately from Eqs. (A2) and (A3). We combine the pricing equations with the first-order conditions for quality (A4) and processes (A5):

$$e_j = \left(\frac{\lambda\varphi A_j}{\beta r} \right)^{\frac{1}{\beta+1-\sigma}} q_j^{\frac{(\sigma-1)(1-\theta)}{\beta+1-\sigma}}, \tag{A6}$$

$$q_j = \left(\frac{\lambda (1-\theta) \kappa A_j}{\alpha r} \right)^{\frac{1}{\alpha+(1-\theta)(1-\sigma)}} e_j^{\frac{\sigma-1}{\alpha+(1-\theta)(1-\sigma)}}, \tag{A7}$$

where market size for domestic producers and exporters is defined as: $A_h = X P^\sigma \left(\frac{\sigma-1}{\sigma}\right)^\sigma$, $A_l = (1+\tau^{1-\sigma})A_h$. Eqs. (A6) and (A7) show the complementary structure of process and quality innovations, as discussed in Section 3.2. Combining the two expressions leads to the optimal investment choices described by Eqs. (9) and (10). By inserting the optimal investment levels into the first order conditions ($A2$) and ($A3$), one obtains the optimal price (12). Total sales of a firm with export status $j \in h, l$ are defined by $s_j(\varphi, \kappa) = XP^{\sigma}\left(\frac{q_j}{p_j}\right)^{\sigma-1} + 1_{\{j=l\}}XP^{\sigma}\left(\frac{q_l}{p_l^*}\right)^{\sigma-1}$, where $p_l^* = \tau p_l$. Inserting the optimal choices of quality innovation (10) and price setting (12) immediately leads to Eq. (15). The optimal loan repayment k_l follows from Eqs. (6) and (7), and can be written as function of revenues:

$$\lambda k_j = rf_j + \frac{\sigma-1}{\sigma}\lambda s_j(z)\left(\frac{1}{\beta} + \frac{1-\theta}{\alpha}\right). \tag{A8}$$

A.2 Derivation of welfare

To derive the welfare function (32), we aggregate the price index (2) as follows:

$$P^{1-\sigma} = M_h \iint_{(\varphi,\kappa)\in D_h} \left(\frac{q_h}{p_h}\right)^{\sigma-1} \mu_h(\varphi,\kappa)d\varphi d\kappa + \left(1+\tau^{1-\sigma}\right) M_l \iint_{(\varphi,\kappa)\in D_l} \left(\frac{q_l}{p_l}\right)^{\sigma-1} \mu_l(\varphi,\kappa)d\varphi d\kappa.$$

We use the firm-specific qualtiy-price ratio in Eq. (14) and exploit the conditions for factor market clearing (26) and (27), which allows to write the inverse price index as follows:

$$P^{-1} = \left(\frac{\sigma-1}{\sigma}\right)^{\frac{\gamma}{\alpha\beta}} \beta^{-\frac{1}{\beta}} \left(\frac{1-\theta}{\alpha}\right)^{\frac{1-\theta}{\alpha}} \left(\frac{\lambda S\left(\frac{\sigma-1}{\sigma}\right)^{\sigma}}{r}\right)^{\frac{\alpha+\beta(1-\theta)}{\alpha\beta}} \left[M_h \widetilde{z}_h^{\frac{\sigma-1}{\gamma}} + \left(1+\tau^{1-\sigma}\right)^{\frac{\alpha\beta}{\gamma}} M_l \widetilde{z}_l^{\frac{\sigma-1}{\gamma}}\right]^{\frac{\gamma}{\alpha\beta(\sigma-1)}}.$$

Analogous to Melitz (2003), we substitute for average levels of combined capability $\widetilde{z}_j$ by using the relationships $\frac{s_j(\widetilde{z}_j)}{s_j(z_j)} = \left(\frac{\widetilde{z}_j}{z_j}\right)^{\frac{\sigma-1}{\gamma}} = \frac{S_j}{M_j}\frac{\gamma\lambda}{\alpha\beta\sigma(r+b)f_j}$, and $\frac{z_l}{z_h} = \left(\frac{f_l}{f_h}\right)^{\frac{\gamma}{\sigma-1}}\left(1+\tau^{1-\sigma}\right)^{\frac{-\alpha\beta}{\sigma-1}}$. After some modifications, this allows to write welfare as a function of the cutoff level of combined capability z_h as shown in Eq. (32).

A.3 Solution with Pareto distributed capabilities

To solve the general equilibrium as described in Section 3, we define the regions of active firms as follows:

$$\begin{aligned} D &= \left\{(\varphi,\kappa) \in [1,\infty] \times [1,\infty] : z \geq z_d\right\}, \\ D_h &= \left\{(\varphi,\kappa) \in [1,\infty] \times [1,\infty] : z_d \leq z < z_x\right\}, \\ D_l &= \left\{(\varphi,\kappa) \in [1,\infty] \times [1,\infty] : z \geq z_x\right\}. \end{aligned}$$

As described in Section 3, we assume that the capability draws are Pareto distributed with positive support over $[1,\infty] \times [1,\infty]$, $g(\varphi,\kappa) = g_{\varphi}(\varphi)g_{\kappa}(\kappa) = \xi\kappa^{-\xi-1}\vartheta\varphi^{-\vartheta-1}$, where ξ and ϑ are the shape parameters of the Pareto distributions. Probabilities of success χ_s and of belonging to the groups of non-exporters and exporters respectively χ_j, as defined in Section 3, can be expressed as functions of the cutoff levels for combined capability z_j:

$$\chi_s = \frac{1}{\Psi} z_h^{\frac{-\xi}{\beta(1-\theta)}}; \chi_h = \frac{1}{\Psi}\left(z_h^{\frac{-\xi}{\beta(1-\theta)}} - z_l^{\frac{-\xi}{\beta(1-\theta)}}\right); \chi_l = \frac{1}{\Psi} z_l^{\frac{-\xi}{\beta(1-\theta)}},$$

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

$$\psi_l = \left(\frac{z_h}{z_l}\right)^{\frac{\xi}{\beta(1-\theta)}}; \psi_h = 1 - \left(\frac{z_h}{z_l}\right)^{\frac{\xi}{\beta(1-\theta)}},$$

with $\frac{z_h}{z_l} = \left(\frac{f_h}{f_l}\right)^{\frac{\gamma}{\sigma-1}} \left(1+\tau^{1-\sigma}\right)^{\frac{\alpha\beta}{\sigma-1}}$. The components of expected profits in Eq. (24) can be expressed as:

$$\psi_h \left(\frac{\widetilde{z}_h}{z_h}\right)^{\frac{\sigma-1}{\gamma}} = \Omega\left(1 - \left(\frac{z_h}{z_l}\right)^{\frac{\xi\gamma-\beta(1-\theta)(\sigma-1)}{\gamma\beta(1-\theta)}}\right), \tag{A9}$$

$$\psi_l \left(\frac{\widetilde{z}_l}{z_l}\right)^{\frac{\sigma-1}{\gamma}} = \Omega\left(\frac{z_h}{z_l}\right)^{\frac{\xi}{\beta(1-\theta)}}, \tag{A10}$$

where $\Omega = \frac{\xi\gamma}{\xi\gamma-\beta(1-\theta)(\sigma-1)}$. The free entry condition (23) is an increasing function of the cutoff level of combined capability z_h:

$$E[\pi] = f_e \Psi z_h^{\frac{\xi}{\beta(1-\theta)}}.$$

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

$$\Delta_z = 1 + \psi_l \frac{f_l}{f_h} \frac{\left(1+\tau^{1-\sigma}\right)^{\frac{\alpha\beta}{\gamma}} - 1}{\left(1+\tau^{1-\sigma}\right)^{\frac{\alpha\beta}{\gamma}}} \; ; \; \widetilde{f} = \psi_h f_h + \psi_l f_l.$$

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

$$z_h = \left(\frac{E[\pi]}{f_e \Psi}\right)^{\frac{\beta(1-\theta)}{\xi}}, \tag{A11}$$

where expected profits can be written as: $E[\pi] = \Omega(r+b)\Delta_z f_h - r\widetilde{f}$.

Number of active firms By combining Eqs. (26) and (27), factor market clearing implies that the number of active firms is given by $M = \frac{(\lambda+r)L}{\lambda\widetilde{s}}$. To solve for the number of firms explicitly, we use the expressions for expected efficiencies of non-exporters and exporters (A9) and (A10). With Pareto distributed capabilities, average revenues can be expressed as:

$$\lambda\widetilde{s} = \frac{\alpha\beta\sigma}{\gamma}\Omega(r+b)\Delta_z f_h,$$

The number of active firms in the differentiated sector is then given by:

$$M = \frac{\gamma}{\alpha\beta\sigma} \frac{(\lambda + r) L}{\Omega (r + b) \Delta_z f_h} , \tag{A12}$$

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

A.4 Proofs

Proof of Proposition 2. The changes of the number of firms with respect to the private benefit b and the borrowing rate r follow immediately from the derivative of Eq. (A12):

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

The derivatives of the cutoff level of combined capability z_h (A11) are given by:

$$\frac{d \ln z_h}{d \ln b} = \frac{\beta(1 - \theta)}{\xi} \frac{\Omega b f_h \Delta_z}{E[\pi]} > 0, \frac{d \ln z_h}{d \ln r} = \frac{\beta(1 - \theta)}{\xi} \frac{\Omega r f_h \Delta_z - r\widetilde{f}}{E[\pi]} > 0. \tag{A13}$$

Proof of Proposition 3. To derive the general equilibrium effects of credit shocks on investment, we solve the cutoff condition (20) for A_j and insert into Eqs. (9) and (10):

$$e_j = \left(\frac{r}{\lambda}\right)^{\frac{-1}{\beta}} \beta^{-\frac{1}{\beta}} \left(\frac{(r + b) f_j}{\lambda \upsilon}\right)^{\frac{1}{\beta}} z_j^{\frac{1-\sigma}{\beta\gamma}} \varphi^{\frac{\alpha + (1-\theta)(1-\sigma)}{\gamma}} \kappa^{\frac{(\sigma-1)(1-\theta)}{\gamma}}, \tag{A14}$$

$$q_j = \left(\frac{r}{\lambda}\right)^{\frac{-1}{\alpha}} \left(\frac{\alpha}{1 - \theta}\right)^{\frac{-1}{\alpha}} \left(\frac{(r + b) f_j}{\lambda \upsilon}\right)^{\frac{1}{\alpha}} z_j^{\frac{1-\sigma}{\alpha\gamma}} \kappa^{\frac{\beta+1-\sigma}{\gamma}} \varphi^{\frac{\sigma-1}{\gamma}}. \tag{A15}$$

Taking the derivatives with respect to b and using that $\frac{d \ln(\lambda \widetilde{s})}{d \ln b} = \frac{b}{r+b}$ (see Prop. 2), leads to Eq. (28). If we insert the derivative of the cutoff level (A13), we obtain:

$$\frac{d \ln e_j}{d \ln b} = \frac{1}{\beta} \frac{b}{r + b} \left(1 - \frac{\beta (\sigma - 1) (1 - \theta)}{\xi\gamma} \frac{E[\pi] + r\widetilde{f}}{E[\pi]}\right), \tag{A16}$$

$$\frac{d \ln q_j}{d \ln b} = \frac{1}{\alpha} \frac{b}{r + b} \left(1 - \frac{\beta (\sigma - 1) (1 - \theta)}{\xi\gamma} \frac{E[\pi] + r\widetilde{f}}{E[\pi]}\right). \tag{A17}$$

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 2), and $\frac{\partial\left(\frac{E[\pi]+r\tilde{f}}{E[\pi]}\right)}{\partial b} < 0$. Hence, the derivatives in Eqs. (A16) and (A17) are positive whenever the private benefit is sufficiently high. The derivatives of the relative investment and the optimal price in Eqs. (11) and (12) can be derived analogously.

Proof of Proposition 4. To obtain Eq. (30), we take the derivatives of Eqs. (A14) and (A15) with respect to the borrowing rate r. We take into account the change in the cutoff level as shown in Eq. (A13), which leads to:

$$\frac{d\ln e_j}{d\ln r} = -\frac{1}{\beta}\left(\frac{b}{r+b} + \frac{\sigma-1}{\gamma}\frac{\beta(1-\theta)}{\xi}\frac{\Omega r f_d \Delta_z - r\widetilde{f}}{\Omega\left(r+b\right) f_d \Delta_z - r\widetilde{f}}\right) < 0. \tag{A18}$$

The changes of all other firm-level variables can be derived analogously.

Proof of Proposition 5. We insert the reaction of the cutoff level (A13) into Eq. (33), which leads to:

$$\frac{d\ln X}{d\ln b} = -\frac{\gamma}{\alpha\beta\left(\sigma-1\right)}\frac{b}{r+b}\left(1 - \frac{\beta(1-\theta)\left(\sigma-1\right)}{\xi\gamma}\frac{E\left[\pi\right]+r\tilde{f}}{E\left[\pi\right]}\right). \tag{A19}$$

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 Prop. 3.

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 Eq. (A13), we can rewrite the welfare response:

$$\frac{d\ln X}{d\ln r} = -\frac{\alpha+\beta\left(1-\theta\right)}{\alpha\beta} - \frac{\gamma}{\alpha\beta\left(\sigma-1\right)}\frac{r}{r+b} + \frac{1-\theta}{\alpha\xi}\frac{\Omega r f_d \Delta_z - r\widetilde{f}}{E\left[\pi\right]}, \tag{A20}$$

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:

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

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 6. We combine Eqs. (29) and (38) to obtain the effect of credit frictions on quantity-based productivity (TFPQ):

$$\frac{d\ln\tilde{\Phi}_j^Q}{d\ln b} = \frac{rf_j}{\lambda\tilde{l}_j + r\tilde{d}_j}\frac{b}{r+b} - \frac{\beta\theta-\alpha}{\alpha\beta}\left(\frac{b}{r+b} - \frac{\sigma-1}{\gamma}\frac{d\ln z_j}{d\ln b}\right). \quad \text{(A22)}$$

By neglecting the last effect of credit frictions on the cutoff level z_j in Eq. (A22), a necessary condition for $\frac{d\ln\tilde{\Phi}_j^Q}{d\ln b} < 0$ is that $\frac{\beta\theta-\alpha}{\alpha\beta} > \frac{rf_j}{\lambda\tilde{l}_j + r\tilde{d}_j}$, which can be written as follows:

$$\frac{\beta\theta-\alpha}{\alpha\beta} > \frac{1}{\frac{\Omega(r+b)}{rv}\left(1+\frac{1}{\beta}+\frac{1-\theta}{\alpha}\right)+1}. \quad \text{(A23)}$$

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 Eq. (A13), a sufficient condition for a negative effect on TFPQ can be written as:

$$\frac{\beta\theta-\alpha}{\alpha\beta}\left(1 - \frac{\beta(1-\theta)(\sigma-1)}{\xi\gamma}\frac{E[\pi]+r\tilde{f}}{E[\pi]}\right) > \frac{1}{\frac{\Omega(r+b)}{rv}\left(1+\frac{1}{\beta}+\frac{1-\theta}{\alpha}\right)+1}. \quad \text{(A24)}$$

From the proof of Prop. 3 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 Eq. (A23), such that lower values of α are required to meet the sufficient condition in Eq. (A24).

B Additional results and extensions of the model

B.1 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.2 Private benefit proportional to loan size

We extend the model by assuming that the private benefit is proportional to the total size of the loan. Compared to Eq. (19) in the main text, this leads to the following incentive compatibility constraint:

$$\lambda \pi_j(z) \geq b\left(f_j + \frac{1}{\kappa}\lambda_j^a(z) + \frac{1}{\varphi}e_j^\beta(z)\right). \tag{B1}$$

We insert profits (16) and investment outlays (17) into Eq. (B1), to obtain a new cutoff condition:

$$\lambda s_j(z_j) = \frac{\sigma(r+b) f_j}{1 - \frac{b+r}{r}(\sigma-1)\left(\frac{1-\theta}{\alpha} + \frac{1}{\beta}\right)}. \tag{B2}$$

In order to ensure a positive cutoff level z_j, we impose that $1 - \frac{b+r}{r}(\sigma-1)\left(\frac{1-\theta}{\alpha} + \frac{1}{\beta}\right) > 0$, which could be rewritten as $b\left(\frac{1-\theta}{\alpha} + \frac{1}{\beta}\right) < vr$. Intuitively, this condition states that the fraction of investment outlays that can be diverted as private benefit must not exceed the share of sales that is earned as operational profit. Otherwise, agents would always have an incentive to shirk, independent of the capability draw. In this case, the financial sector will not provide credit to any firm.

The comparison of Eq. (B2) with Eq. (21) immediately shows that the cutoff level of the extended model is larger. Hence, assuming that private benefits are also proportional to investment outlays, increases the impact of credit frictions and makes credit access more difficult for low capability firms. Note, however, that the qualitative results remain unchanged compared to the model presented in the main text.

B.3 External financing of fixed entry costs

In this section, we discuss how external financing of fixed entry costs f_e would affect the implications of our model. We consider two effects related to financial shocks. First, external financing of fixed entry costs implies that firms face interest payments rf_e. Second, the moral hazard problem could be related to fixed entry costs as assumed for fixed production costs in the main text, such that bf_e is an additional private benefit of shirking. From the equilibrium condition in Eq. (A11) follows that both credit costs and private benefits related to fixed entry costs will decrease the cutoff level z_h. Intuitively, higher credit costs and stronger credit frictions aggravate entry of potential producers. As a consequence, reduced entry lowers competition for existing firms, which allows more low capability firms to survive.

As in our main model, credit frictions lead to reduced competition for existing producers, though working through a different channel, namely the entry stage. From Eq. (32) follows that a reduction in the cutoff level z_h leads to a welfare loss, as the average quality-price ratio decreases. Most importantly, we show that the differential implications of credit frictions on prices, depending on the scope for vertical product differentiation, remain valid when fixed entry costs are financed externally. To see this, we show the price reaction to credit frictions if the private benefit b is related to both fixed production costs and fixed entry costs:

$$\frac{d\ln p_j}{d\ln b} = \frac{\beta\theta - \alpha}{\alpha\beta}\left[\frac{b}{r+b} + \frac{1-\sigma}{\gamma}\left(\underbrace{\frac{d\ln z_j}{d\ln b}}_{>0} + \underbrace{\frac{d\ln z_h}{d\ln b}}_{<0}\right)\right]. \tag{B3}$$

Note that $\frac{b}{r+b} + \frac{1-\sigma}{\gamma}\frac{d\ln z_j}{d\ln b} > 0$ whenever the private benefit is sufficiently large (see Prop. 3). Compared to the price reaction in Eq. (29), the last term of Eq. (B3) captures the additional impact of credit frictions on the entry cutoff level. Note that this effect goes in the same direction as the direct impact of b in the main model, such that the direction of the price reaction remains unchanged and hence is still given by the scope for vertical product differentiation.

We additionally consider the effect of credit costs on prices if external finance is also needed for fixed entry costs:

$$\frac{d\ln p_j}{d\ln r} = \frac{\alpha - \beta\theta}{\alpha\beta}\left[\frac{b}{r+b} + \frac{\sigma-1}{\gamma}\left(\underbrace{\frac{d\ln z_j}{d\ln r}}_{>0} + \underbrace{\frac{d\ln z_h}{d\ln r}}_{<0}\right)\right]. \tag{B4}$$

Compared to Eq. (31), the selection effect related to fixed entry costs works in the opposite reaction than the impact of credit costs in the main model. If credit costs for entry rf_e enter into Eq. (A11), then $\frac{d\ln z_h}{d\ln r} = -\frac{\beta(1-\theta)}{\xi}$. Inserting this derivative together with Eq. (A13) into Eq. (B4), leads to:

$$\frac{d\ln p_j}{d\ln r} = \frac{\alpha - \beta\theta}{\alpha\beta}\frac{b}{r+b}\left[1 - \frac{\beta\,(\sigma-1)\,(1-\theta)}{\xi\gamma}\frac{E[\pi] + r\widetilde{f}}{E[\pi]}\right]. \tag{B5}$$

Note that the term in brackets is positive whenever the condition in the proof of Prop. 4 holds. Hence, if the private benefit is sufficiently large, then credit costs lead to the same price effects as in the main model.

B.4 Capital market equilibrium with endogenous interest rate

In this section, we show that the model's main implications remain valid when we allow for endogenous adjustments of the interest rate. Using that average capital demand is given by $\widetilde{d} = \widetilde{f} + \frac{\lambda\widetilde{s}}{r}\frac{\alpha\beta-\gamma}{\alpha\beta\sigma}$, and average sales are $\lambda\widetilde{s} = \frac{\alpha\beta\sigma}{\gamma}\Omega\,(r+b)\,\Delta_z f_h$, we rewrite the capital market clearing condition in Eq. (40) as follows:

$$\frac{K}{\lambda L} = \frac{\frac{\alpha\beta-\gamma}{\gamma}\frac{r+b}{r}\Omega\Delta_z f_h + \widetilde{f}}{\frac{\alpha\beta(\sigma-1)+\gamma}{\gamma}\,(r+b)\,\Omega\Delta_z f_h - r\widetilde{f}}. \tag{B6}$$

The effect of credit frictions b on the interest rate follows from the derivative of Eq. (B6), while using the labor market and capital market clearing conditions (26) and (40):

$$\frac{d\ln r}{d\ln b} = -\frac{\left(1+\frac{rK}{\lambda L}\right)\widetilde{f}}{\left(1+\frac{r}{b}\right)\frac{K}{M} - \left(1+\frac{rK}{\lambda L}\right)\widetilde{f}} < 0. \tag{B7}$$

The effect of credit frictions on the number of firms can be derived from the labor market condition (26):

$$\frac{d\ln M}{d\ln b} = \frac{-\left(\frac{\lambda L}{M}+r\widetilde{f}\right) - \left(\frac{\lambda L}{M}-b\widetilde{f}\right)\frac{r}{b}\frac{d\ln r}{d\ln b}}{\left(1+\frac{r}{b}\right)\frac{\lambda L}{M}},$$

where the first term represents the direct negative effect of credit frictions, and the second term shows a counteracting effect due to a decrease in the interest rate. Inserting the effect on the interest rate in Eq. (B7) shows that the overall effect of credit frictions on the number of firms is negative:

$$\frac{d\ln M}{d\ln b} = \frac{-\frac{K}{M}+\widetilde{f}}{\left(1+\frac{r}{b}\right)\frac{K}{M} - \left(1+\frac{rK}{\lambda L}\right)\widetilde{f}} < 0,$$

where $\frac{K}{M} - \widetilde{f} > 0$ captures the average capital demand for endogenous innovation outlays.

The effect of credit frictions on the cutoff efficiency level (A11) is given by:

$$\frac{d\ln z_h}{d\ln b} = \frac{\beta(1-\theta)}{\xi}\frac{\Omega b\Delta_z f_h + r\left(\Omega\Delta_z f_h - \widetilde{f}\right)\frac{d\ln r}{d\ln b}}{E\left[\pi\right]}, \tag{B8}$$

where inserting the reaction of the interest rate (B7) leads to:

$$\frac{d\ln z_h}{d\ln b} = \frac{\beta(1-\theta)}{\xi}\frac{\Omega\,(b+r)\,\Delta_z f_h\left[\frac{K}{M} - \left(1+\frac{rK}{\lambda L}\right)\widetilde{f}\right] + r\left(1+\frac{rK}{\lambda L}\right)\widetilde{f}^2}{E\left[\pi\right]\left[\left(1+\frac{r}{b}\right)\frac{K}{M} - \left(1+\frac{rK}{\lambda L}\right)\widetilde{f}\right]}.$$

A sufficient condition for $\frac{d\ln z_h}{d\ln b} > 0$ is that $\frac{K}{M} > \left(1 + \frac{rK}{L}\right)\widetilde{f}$, which can be rewritten as $\frac{\alpha\beta-\gamma}{\gamma}\frac{\Omega(r+b)\Delta_z f_h}{r\widetilde{f}} > \frac{rK}{L}$. Note that the LHS of this inequality increases in credit frictions b, while the RHS decreases in b: $\frac{d\left(\frac{rK}{L}\right)}{db} = -\frac{\frac{\alpha\beta}{\gamma}\Omega\Delta_z f_h r\tilde{f}}{\left(\frac{\alpha\beta(\sigma-1)+\gamma}{\gamma}\Omega(r+b)\Delta_z f_h - r\tilde{f}\right)^2} < 0$. Hence, the condition is satisfied whenever credit frictions are sufficiently large. These derivations show that the results of Prop. 2 remain valid even if we take into account endogenous adjustments of the interest rate.

We further show that the firm-level responses to credit frictions as summarized in Prop. 3 remain robust. In particular, the negative adjustment of the interest rate reinforces the positive reactions of investments compared to Eq. (28) in the main text:

$$\frac{d\ln e_j}{d\ln b} = \frac{1}{\beta}\frac{b}{r+b}\left(1 - \frac{d\ln r}{d\ln b}\right) - \frac{\sigma-1}{\beta\gamma}\frac{d\ln z_j}{d\ln b},$$

$$\frac{d\ln q_j}{d\ln b} = \frac{1}{\alpha}\frac{b}{r+b}\left(1 - \frac{d\ln r}{d\ln b}\right) - \frac{\sigma-1}{\alpha\gamma}\frac{d\ln z_j}{d\ln b}.$$

Analogously, the price reaction with endogenous interest rate adjustment can be written as:

$$\frac{d\ln p_j}{d\ln b} = \frac{\beta\theta-\alpha}{\alpha\beta}\left[\frac{b}{r+b}\left(1 - \frac{d\ln r}{d\ln b}\right) + \frac{1-\sigma}{\gamma}\frac{d\ln z_j}{d\ln b}\right]. \quad \text{(B9)}$$

The comparison with Eq. (29) shows that the endogenous adjustment of the interest rate works in the same direction as the direct effect of credit frictions. Hence, the price response becomes quantitatively larger while the direction of the effect is still determined by the scope for vertical product differentiation as highlighted in Prop. 3.

The effect of credit frictions on welfare (32) contains now two additional adjustments compared to Eq. (33):

$$\frac{d\ln X}{d\ln b} = \frac{\sigma}{\sigma-1}\frac{d\ln r}{d\ln b}\frac{rK}{I} - \frac{\gamma}{\alpha\beta(\sigma-1)}\frac{b}{r+b} - \frac{\alpha\beta r + (\alpha\beta-\gamma)b}{\alpha\beta(\sigma-1)(r+b)}\frac{d\ln r}{d\ln b} + \frac{1}{\alpha\beta}\frac{d\ln z_h}{d\ln b}. \quad \text{(B10)}$$

First, the reduction in the interest rate leads to a decrease in income. Second, there is a counteracting welfare effect as stronger credit frictions reduce borrowing costs leading to larger investments. Taking into account the negative response of the interest rate (B7) implies that a necessary condition for welfare losses from credit frictions is given by:

$$-\frac{\gamma}{\alpha\beta(\sigma-1)}\frac{b}{r+b} + \frac{\alpha\beta r + (\alpha\beta-\gamma)b}{\alpha\beta(\sigma-1)(r+b)}\frac{\left(1+\frac{rK}{\lambda L}\right)\widetilde{f}}{\left(1+\frac{r}{b}\right)\frac{K}{M} - \left(1+\frac{rK}{\lambda L}\right)\widetilde{f}} < 0.$$

This condition can be simplified to: $\frac{\gamma}{\alpha\beta}\frac{K}{M} > \left(1+\frac{rK}{\lambda L}\right)\widetilde{f}$, which is again satisfied if credit frictions are sufficiently large. As shown in Eq. (B8), note that the positive reaction of the cutoff level is reduced in the presence of endogenous interest rate adjustments. Hence, together with the condition from the proof of Prop. 5, this establishes that welfare losses occur if credit frictions are sufficiently large.

We further show that allowing for endogenous interest rate adjustments does not change the main results on productivity in Section 4. In particular, the positive effect of credit frictions on TFPR in Eq. (37) is intensified due to a decrease in the borrowing rate ($\frac{d\ln r}{d\ln b} < 0$):

$$\frac{d\ln\tilde{\Phi}_j^R}{d\ln b} = \frac{rf_j}{\lambda\tilde{l}_j + r\tilde{d}_j}\frac{b}{r+b}\left(1 - \frac{d\ln r}{d\ln b}\right) > 0.$$

Note that Eq. (B9) shows that the additional effect on the interest rate increases the direct effect on prices in the same way. Hence, the proof of Prop. 6 remains valid as the direction of the price change with respect to credit frictions is still determined by the scope for vertical product differentiation.

Besides the implications of credit frictions, the effects of changes in the interest rate can be obtained by comparative statistics with respect to inelastic capital supply in the differentiated sector. From Eq. (B6) follows that: $\frac{d\ln r}{d\ln\left(\frac{K}{\lambda L}\right)} = -\frac{\left(1+\frac{r}{b}\right)\frac{K}{M}}{\left(1+\frac{r}{b}\right)\frac{K}{M} - \left(1+\frac{rK}{\lambda L}\right)\hat{f}} < 0$. In this context, the discussed interest rate effects in the main text can be interpreted as reductions in capital supply.

C Data sources and counterfactual analysis

This section outlines the calibration of of our framework with two types of innovation, and of three model variants that are nested as special cases: (i) only quality innovations, (ii) only process innovations, (iii) no endogenous innovations. For the counterfactual analysis, we use firm-level data for Colombia from the World Bank Enterprise Surveys in 2017. The data contain a representative sample of 993 Colombian firms, covering the fiscal year 2016. The robustness checks provide further results for Mexico based on information of 1480 firms in 2009, and for 1003 firms from Peru in 2016. As described in Section 5, in all variants we target the ratio of labor costs relative to sales to obtain a measure for the elasticity of substitution: $\sigma = \frac{1}{1-l_j(z)/s_j(z)}$. The Enterprise Surveys provide firm-level information on total annual sales and costs of labor including wages, salaries, and bonuses. We compute the mean of the labor costs to sales ratio by sector to obtain the corresponding values for the elasticity of substitution σ.

C.1 Model with two types of innovation

We use the investment to sales ratios in Eq. (17), which allows to obtain values for the investment cost parameters:

$$\alpha = \frac{(\sigma-1)(1-\theta)}{\sigma}\frac{s_j(z)}{\frac{r}{\kappa}q_j^{\alpha}(z)};\ \beta = \frac{\sigma-1}{\sigma}\frac{s_j(z)}{\frac{r}{\varphi}e_j^{\beta}(z)}. \tag{C1}$$

We target the mean ratio of process innovations relative to sales by sector using reported annual expenditures on machinery, vehicles, and equipment. Analogously, we use annual expenditures on research and development activities as a proxy for quality innovations to compute the ratio of investments to sales in Eq. (C1). Note that this approach allows to identify the parameter α conditional on a chosen value for θ. Flach and Unger (2021) provide estimates for the joint parameter $(1-\theta)/\alpha$ across 4-digit industries in a gravity framework with quality innovations. Using the average across industries (0.046) from Table B.17 in Flach and Unger (2021) and our average estimate for $\alpha = 4.669$ from Table 1 leads to $\theta = 0.78$, which is our preferred parameter choice in the baseline specification. We also provide results for a lower marginal cost elasticity ($\theta = 0.75$). Given values for variable trade costs τ and the Pareto shape parameter ξ, the share of exporters in Eq. (41) allows to solve for relative fixed export costs:

$$\frac{f_l}{f_h} = \psi_l^{-\frac{\beta(\sigma-1)(1-\theta)}{\xi\gamma}}\left(1+\tau^{1-\sigma}\right)^{\frac{\alpha\beta}{\gamma}}. \tag{C2}$$

As described in Section 5, it follows from Eq. (27) that the capital amount relative to sales is given by $\frac{K}{S} = \frac{\widetilde{f}}{\lambda\tilde{s}} + \frac{\alpha\beta-\gamma}{\alpha\beta\sigma r}$, and depends negatively on credit frictions captured by the private benefit b. Inserting average sales $\lambda\widetilde{s} = \frac{\alpha\beta\sigma}{\gamma}\Omega(r+b)\Delta_z f_h$ leads to:

$$\frac{K}{S} = \frac{\tilde{d}}{\tilde{s}} = \frac{1}{\alpha\beta\sigma}\left(\frac{\gamma\widetilde{f}}{\Omega(r+b)\Delta_z f_h} + \frac{\alpha\beta-\gamma}{r}\right).$$

Solving the previous equation for the private benefits yields:

$$b = \frac{\gamma\frac{\widetilde{f}}{f_h}}{\Omega\Delta_z\left[\alpha\beta\sigma\left(\frac{\tilde{d}}{\tilde{s}}\right) - \frac{\alpha\beta-\gamma}{r}\right]} - r. \tag{C3}$$

We use the ratio of private credit to GDP as a proxy for K/S, which was 0.471 for Colombia in 2016, as reported by the World Bank's Financial Development Indicators. Together with the estimated parameters from the preceding steps, this allows us to compute sector-specific values for the private benefit b. For this purpose, we have chosen the success probability $\lambda = 0.873$, such that $\frac{r}{\lambda} = 1.146$, which matches the lending interest rate for Columbia in 2016 from the World Bank Development Indicators, where r is normalized to one. Table 1 summarizes targeted moments and parameter estimates based on Eqs. (C1)-(C3).

C.2 Model with only quality innovations

This variant allows firms to conduct only quality innovations but no process innovations, where the cost-based capability $\varphi = 1$ for all firms. Hence, compared to Eq. (5), marginal production costs are now given by $mc\left(q_j\right) = q_j^{\theta}$, with $0 < \theta < 1$. The optimal firm-level price is then $p_j\left(\varphi, \kappa\right) = \frac{\sigma}{\sigma-1} q_j^{\theta}$, where the level of endogenous quality innovations can be written as:

$$q_j = \left(\frac{\lambda\left(1-\theta\right)\kappa A_j}{\alpha r}\right)^{\frac{1}{\alpha+(1-\theta)(1-\sigma)}}. \tag{C4}$$

Total sales of a firm with capability κ are given by:

$$s_j\left(\kappa\right) = \frac{\sigma}{\sigma-1} A_j^{\frac{\alpha}{\gamma}} \left(\frac{\lambda\left(1-\theta\right)}{\alpha r}\kappa\right)^{\frac{(\sigma-1)(1-\theta)}{\gamma_q}}, \tag{C5}$$

where $\gamma_q \equiv \alpha + \left(1-\sigma\right)\left(1-\theta\right) > 0$. In contrast to the model with two types of innovation, we only target investment costs of quality innovations relative to sales: $\frac{\frac{r}{\kappa} q_j^{\alpha}(\kappa)}{s_j(\kappa)} = \frac{(\sigma-1)(1-\theta)}{\alpha\sigma}$. Analogous to Eq. (41), the share of exporters is now given by:

$$\frac{f_l}{f_h} = \psi_l^{-\frac{\sigma-1}{\xi\gamma_q}} \left(1+\tau^{1-\sigma}\right)^{\frac{\alpha}{\gamma_q}}. \tag{C6}$$

In the absence of process innovations, the budget constraint (6) simplifies to $d_j \geq f_j + \frac{1}{\kappa} q_j^{\alpha}$. Hence, the capital-to-sales ratio can now be written as:

$$\frac{K}{S} = \frac{\widetilde{f}}{\lambda\tilde{s}} + \frac{\sigma-1}{\sigma}\frac{1-\theta}{\alpha r}. \tag{C7}$$

Analogous to the equilibrium as presented in Section 3 and Appendix A.3, expected profits by group of (non-)exporters can be written as $E\left[\pi_j\right] = \frac{\sigma-1}{\sigma}\left(\frac{1}{\sigma-1} - \frac{1-\theta}{\alpha}\right)\lambda\widetilde{s}_j - r f_j$, where average sales can be expressed as $\lambda\widetilde{s} = \frac{\alpha\sigma(r+b)\Omega_q f_h \Delta_{zq}}{\alpha-(1-\theta)(\sigma-1)}$, with $\Delta_{zq} \equiv 1 + \psi_l \frac{f_l}{f_h} \frac{\left(1+\tau^{1-\sigma}\right)^{\frac{\alpha}{\gamma}}-1}{\left(1+\tau^{1-\sigma}\right)^{\frac{\alpha}{\gamma}}}$, and $\Omega_q \equiv \frac{\xi\gamma}{\xi\gamma-(1-\theta)(\sigma-1)}$. Using the expression of average sales together with Eq. (C7) allows to obtain a value for the private benefit as a function of investment cost parameters, trade costs and the ratio of credit to sales:

$$b=\frac{\gamma_q\frac{\widetilde{f}}{f_h}}{\Omega_q\Delta_{zq}\left[\alpha\sigma\left(\frac{\tilde{d}}{\lambda\tilde{s}}\right)-\frac{(1-\theta)(\sigma-1)}{r}\right]}-r. \tag{C8}$$

Table D1 summarizes the parameter estimates based on Eqs. (C5)-(C8). We further show the theoretical counterparts of the effects presented in Panel B of Table 2. Analogous to Eq. (37), the average values of TFPR and TFPQ can be written as follows:

$$\widetilde{\Phi}_j^R=\frac{\frac{\sigma}{\sigma-1}\left(\frac{\widetilde{\kappa}_j}{\kappa_j}\right)^{\frac{\sigma-1}{\gamma}}}{\left(1+\frac{1-\theta}{\alpha}\right)\left(\frac{\widetilde{\kappa}_j}{\kappa_j}\right)^{\frac{\sigma-1}{\gamma}}+\left(\frac{1}{\sigma-1}-\frac{1-\theta}{\alpha}\right)\frac{r}{r+b}};\widetilde{\Phi}_j^Q=\frac{\widetilde{\Phi}_j^R}{\widetilde{p}_j}, \tag{C9}$$

where the effect of credit frictions b is clearly positive. The same holds for the reaction of the average price:

$$\frac{d\ln p_j\left(\widetilde{\kappa}_j\right)}{d\ln b}=\frac{\theta}{\alpha}\left(\frac{b}{r+b}+\frac{d\ln\kappa_j}{d\ln b}\right)>0, \tag{C10}$$

where the effect on the cutoff level of the quality-based capability is given by:

$$\frac{d\ln\kappa_h}{d\ln b}=\frac{1}{\xi}\frac{\Omega_q bf_h\Delta_{zq}}{\Omega_q\left(r+b\right)f_h\Delta_{zq}-r\widetilde{f}}>0. \tag{C11}$$

Finally, the effect of credit frictions on welfare in the presence of only quality innovations is:

$$\frac{d\ln W}{d\ln b}=-\frac{\gamma_q}{\alpha\left(\sigma-1\right)}\frac{b}{r+b}+\frac{1-\theta}{\alpha}\frac{d\ln\kappa_h}{d\ln b}. \tag{C12}$$

C.3 Model with only process innovation

If we allow only for process innovation, we set the quality level $q_i=1\ \forall i$, and consider only heterogeneity in cost-based capability, such that $z=\varphi$. Firm-level prices are negatively related to the level of process innovations: $p_j=\frac{\sigma}{\sigma-1}\frac{1}{e_j}$. The optimal level of process innovations and firm-level sales can be written as follows:

$$e_j\left(\varphi\right)=\left(\frac{\lambda}{r}\frac{\varphi}{\beta}A_j\right)^{\frac{1}{\beta-\sigma+1}};\ s_j\left(\varphi\right)=\frac{\sigma}{\sigma-1}A_j^{\frac{\beta}{\beta-\sigma+1}}\left(\frac{\lambda}{r}\frac{\varphi}{\beta}\right)^{\frac{\sigma-1}{\beta-\sigma+1}}. \tag{C13}$$

The share of exporters is now determined by:

$$\psi_l=\left(\frac{f_l}{f_h}\right)^{-\frac{\xi(\beta-\sigma+1)}{\sigma-1}}\left(1+\tau^{1-\sigma}\right)^{\frac{\xi\beta}{\sigma-1}}. \tag{C14}$$

As firms have to finance fixed costs and innovation outlays for processes, the budget constraints states that $d_j \geq f_j + \frac{1}{\varphi} e_j^{\beta}$. Hence, the ratio of investment costs for process innovations relative to sales is $\frac{\frac{r}{\varphi_j} e_j^{\beta}(\varphi_j)}{s_j(\varphi_j)} = \frac{\sigma-1}{\sigma\beta}$. Accordingly, the capital amount relative to sales is:

$$\frac{K}{S} = \frac{\tilde{d}}{\lambda\tilde{s}} = \frac{\widetilde{f}}{\lambda\tilde{s}} + \frac{\sigma-1}{\sigma r \beta}. \tag{C15}$$

Assuming that the cost-based capability is Pareto distributed allows to write average sales as $\lambda\widetilde{s} = \frac{\sigma\beta(r+b)\Omega_p f_h \Delta_{zp}}{\beta-(\sigma-1)}$, where $\Delta_{zp} \equiv 1 + \psi_l \frac{f_l}{f_h} \frac{\left(1+\tau^{1-\sigma}\right)^{\frac{\beta}{\beta-\sigma+1}}-1}{\left(1+\tau^{1-\sigma}\right)^{\frac{\beta}{\beta-\sigma+1}}}$, and $\Omega_p \equiv \frac{\xi(\beta-\sigma+1)}{\xi(\beta-\sigma+1)-\sigma+1}$. Solving for the private benefit yields:

$$b = \frac{(\beta-\sigma+1)\frac{\widetilde{f}}{f_h}}{\Omega_p \Delta_{zp}\left[\beta\sigma\left(\frac{\tilde{d}}{\lambda\tilde{s}}\right) - \frac{\sigma-1}{r}\right]} - r. \tag{C16}$$

The effects of credit frictions as presented in Panel C of Table 2 are based on the following equations. Computing the average value of TFPR now leads to:

$$\widetilde{\Phi}_j^R = \frac{\frac{\sigma}{\sigma-1}\left(\frac{\widetilde{\varphi}_j}{\varphi_j}\right)^{\frac{\sigma-1}{\beta-\sigma+1}}}{\left(1+\frac{1}{\beta}\right)\left(\frac{\widetilde{\varphi}_j}{\varphi_j}\right)^{\frac{\sigma-1}{\beta-\sigma+1}} + \left(\frac{1}{\sigma-1} - \frac{1}{\beta}\right)\frac{r}{r+b}}. \tag{C17}$$

The effect of credit frictions on the average price is clearly negative:

$$\frac{d\ln p_j\left(\widetilde{\varphi}_j\right)}{d\ln b} = -\frac{1}{\beta}\left(\frac{b}{r+b} + \frac{d\ln\varphi_j}{d\ln b}\right) < 0, \tag{C18}$$

where exit of the least productive firms leads to a higher cutoff productivity level:

$$\frac{d\ln\varphi_h}{d\ln b} = \frac{1}{\xi}\frac{\Omega_p b f_h \Delta_{zp}}{\Omega_p (r+b) f_h \Delta_{zp} - r\widetilde{f}} > 0. \tag{C19}$$

This implies a positive reaction of TFPQ to credit frictions $\left(\frac{d\ln\tilde{\Phi}_j^Q}{d\ln b} = \frac{d\ln\tilde{\Phi}_j^R}{d\ln b} - \frac{d\ln\tilde{p}_j}{d\ln b} > 0\right)$. The welfare effect is given by:

$$\frac{d\ln W}{d\ln b} = -\frac{1}{\beta}\left(\frac{\beta-\sigma+1}{\sigma-1}\frac{b}{r+b} - \frac{d\ln\varphi_h}{d\ln b}\right). \tag{C20}$$

C.4 Model without endogenous innovations

Without endogenous innovations, firms only differ in cost-based capability φ that resembles the exogenous draw in a Melitz (2003)-type model, where marginal production costs are just given by the inverse of this productivity measure. The share of exporters is given by:

$$\psi_l = \left(\frac{f_l}{f_h}\right)^{-\frac{\xi}{\sigma-1}} \left(1+\tau^{1-\sigma}\right)^{\frac{\xi}{\sigma-1}}. \tag{C21}$$

With Pareto distributed productivity φ, average sales are $\lambda\widetilde{s} = \sigma\Omega_o (r+b)\Delta_{zo} f_h$. In this case, note that $\Omega_o \equiv \frac{\xi}{\xi-\sigma+1}$, and $\Delta_{zo} \equiv 1 + \psi_l \frac{f_l}{f_h}\frac{\tau^{1-\sigma}}{1+\tau^{1-\sigma}}$. In the absence of endogenous innovations, firms finance only fixed costs of production and of exporting by external credit. This implies that the total credit amount relative to total sales simplifies to $\frac{K}{S} = \frac{\tilde{d}}{\lambda\tilde{s}} = \frac{\widetilde{f}}{\sigma\Omega_o(r+b)\Delta_{zo}f_h}$, which allows to solve for the private benefit:

$$b = \frac{\frac{\widetilde{f}}{f_h}}{\sigma\Omega_o\Delta_{zo}\left(\frac{\tilde{d}}{\lambda\tilde{s}}\right)} - r. \tag{C22}$$

In this benchmark case, the only effect how credit frictions affect average prices is due to exit of low productivity firms, such that prices decrease: $\frac{d\ln p_j(\widetilde{\varphi}_j)}{d\ln b} = -\frac{d\ln\varphi_j}{d\ln b} < 0$, where the effect on the cutoff productivity can now be written as:

$$\frac{d\ln\varphi_h}{d\ln b} = \frac{1}{\xi}\frac{\Omega_o b f_h \Delta_{zo}}{\Omega_o (r+b) f_h\Delta_{zo} - r\widetilde{f}} > 0. \tag{C23}$$

Deriving the effect of credit frictions on welfare leads to:

$$\frac{d\ln W}{d\ln b} = -\frac{1}{\sigma-1}\frac{b}{r+b} + \frac{d\ln\varphi_h}{d\ln b}. \tag{C24}$$

Average TFPR is now given by $\tilde{\Phi}_j^R = \frac{\frac{\sigma}{\sigma-1}\left(\frac{\tilde{\varphi}_j}{\varphi_j}\right)^{\sigma-1}}{\left(\frac{\tilde{\varphi}_j}{\varphi_j}\right)^{\sigma-1} + \frac{1}{\sigma-1}\frac{r}{r+b}}$, such that the effect on average TFPQ is always positive: $\frac{d\ln\tilde{\Phi}_j^Q}{d\ln b} = \frac{d\ln\tilde{\Phi}_j^R}{d\ln b} + \frac{d\ln\varphi_j}{d\ln b} > 0$.

D Results of counterfactual analysis

Table D1: Parameter estimates by sector for benchmark cases

			Only quality innovation			Only process innovation			No innovation	
Sector	Code	σ	α	f_l/f_h	b	β	f_l/f_h	b	f_l/f_h	b
15	Food	1.233	1.519	2.095	0.772	1.903	2.216	0.772	2.132	0.624
17	Textiles	1.443	8.104	1.838	0.482	4.176	1.998	0.749	2.085	0.309
18	Garments	1.402	4.018	1.886	0.535	5.981	1.926	0.685	2.028	0.361
19	Leather	1.459	13.090	1.807	0.461	3.811	1.993	0.877	1.983	0.281
20	Wood	1.330	4.379	1.911	0.615	11.974	1.891	0.659	2.076	0.467
22	Publishing, printing	1.414	11.624	1.837	0.509	1.721	2.460	0.509	2.121	0.349
24	Chemicals	1.278	0.848	2.170	0.760	2.874	2.056	1.371	2.024	0.546
25	Plastics and rubber	1.202	0.931	2.090	0.841	1.740	2.144	0.841	2.010	0.676
26	Non-metal. mineral prod.	1.235	2.447	1.945	0.745	3.004	2.020	1.548	1.971	0.611
28	Fabricated metal products	1.375	1.091	2.229	0.630	3.542	2.052	0.891	2.128	0.403
29	Machinery and equipment	1.406	1.258	2.153	0.583	3.830	2.026	0.826	2.105	0.359
31	Electronics	1.364	6.916	1.878	0.568	8.894	1.905	0.636	2.124	0.418
33	Precision instruments	1.243	4.555	1.917	0.723	1.792	2.151	0.723	1.988	0.600
34	Transport machines	1.186	5.728	1.929	0.801	4.696	1.976	1.117	1.990	0.705
36	Furniture	1.235	1.281	2.073	0.780	3.179	2.039	1.216	2.052	0.621
45	Construction Section F	1.362	12.947	1.878	0.564	5.233	2.039	0.631	2.517	0.404
51	Wholesale	1.170	3.023	1.984	0.836	2.255	2.100	1.366	2.081	0.740
52	Retail	1.206	1.279	2.328	0.802	0.701	3.890	0.904	2.374	0.655
55	Hotel and restaurants	1.328	9.622	1.874	0.607	3.595	2.037	0.953	2.099	0.471
60	Transport Section	1.587	2.486	2.115	0.367	1.141	6.380	0.367	2.586	0.137
72	IT	1.640	0.902	2.644	0.397	8.409	1.850	0.349	2.214	0.088
	Average	1.338	4.669	2.028	0.637	4.021	2.340	0.856	2.128	0.468

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

Table D2: Robustness check - quantification of model when including costs for electricity

Code	Sector	cost/ sales	σ	Paramter values α	β	f_l/f_h	b	Effects of stronger credit frictions Price	TFPR	TFPQ	Welfare
15	Food	0.212	1.268	1.703	2.132	2.149	0.901	-0.004	0.240	0.244	-1.442
17	Textiles	0.293	1.414	7.728	3.982	1.956	0.602	-0.056	0.192	0.247	-0.793
18	Garments	0.293	1.413	4.100	6.103	1.924	0.571	0.010	0.194	0.184	-0.783
19	Leather	0.294	1.416	12.222	3.558	1.963	0.611	-0.082	0.190	0.272	-0.793
20	Wood	0.260	1.351	4.587	12.542	1.894	0.608	0.034	0.227	0.193	-1.012
22	Publishing, printing	0.312	1.453	12.381	1.833	2.188	0.731	-0.202	0.159	0.361	-0.689
24	Chemicals	0.232	1.302	0.904	3.064	2.158	0.834	0.230	0.220	-0.010	-1.171
25	Plastics and rubber	0.209	1.264	1.155	2.158	2.165	0.926	0.099	0.237	0.138	-1.448
26	Non-metal. mineral prod.	0.244	1.323	3.139	3.853	1.991	0.717	-0.004	0.228	0.232	-1.131
28	Fabricated metal products	0.297	1.423	1.190	3.863	2.142	0.643	0.144	0.173	0.029	-0.694
29	Machinery and equipment	0.290	1.408	1.261	3.842	2.116	0.656	0.133	0.180	0.047	-0.744
31	Electronics	0.273	1.376	7.082	9.107	1.890	0.586	0.000	0.215	0.214	-0.920
33	Precision instruments	0.201	1.252	4.686	1.843	2.099	0.923	-0.178	0.252	0.430	-1.605
34	Transport machines	0.177	1.215	6.485	5.316	1.957	0.811	-0.030	0.298	0.328	-1.969
36	Furniture	0.199	1.248	1.340	3.326	2.070	0.850	0.126	0.260	0.134	-1.585
45	Construction Section F	0.301	1.431	14.668	5.929	1.900	0.545	-0.040	0.190	0.230	-0.749
51	Wholesale	0.158	1.188	3.300	2.461	2.042	0.929	-0.081	0.303	0.384	-2.309
52	Retail	0.181	1.221	1.356	0.743	2.747	1.709	-0.471	0.192	0.664	-1.857
55	Hotel and restaurants	0.286	1.400	11.122	4.156	1.944	0.610	-0.064	0.199	0.263	-0.843
60	Transport Section	0.372	1.592	2.502	1.148	3.851	1.293	-0.293	0.077	0.370	-0.384
72	IT	0.404	1.677	0.932	8.693	2.171	0.310	0.129	0.090	-0.039	-0.200
	Average	0.261	1.364	4.945	4.269	2.158	0.779	-0.029	0.206	0.234	-1.101

Calibration of model for Colombia with alternative values for elasticity of substitution σ. Ratio of costs over sales includes annual expenditures for labor and electricity. Data: World Bank Enterprise Surveys 2017, World Bank Financial Development Indicators.

Table D3: Robustness check - alternative marginal cost parameter

Code	Sector	Parameter values α	β	f_l/f_h	b	Effects of credit frictions Price	TFPR	TFPQ	Welfare
15	Food	1.750	1.903	2.162	0.967	-0.046	0.257	0.304	-1.737
17	Textiles	9.336	4.176	1.945	0.565	-0.057	0.181	0.237	-0.710
18	Garments	4.629	5.981	1.929	0.585	-0.002	0.199	0.201	-0.819
19	Leather	15.080	3.811	1.946	0.557	-0.075	0.175	0.250	-0.675
20	Wood	5.045	11.974	1.903	0.634	0.025	0.236	0.212	-1.108
22	Publishing, printing	13.392	1.721	2.199	0.795	-0.231	0.171	0.402	-0.799
24	Chemicals	0.976	2.874	2.166	0.876	0.185	0.231	0.046	-1.316
25	Plastics and rubber	1.073	1.740	2.186	1.047	0.061	0.268	0.207	-2.038
26	Non-metal. mineral prod.	2.820	3.004	2.028	0.855	-0.030	0.272	0.303	-1.734
28	Fabricated metal products	1.257	3.542	2.156	0.716	0.122	0.191	0.069	-0.849
29	Machinery and equipment	1.449	3.830	2.116	0.659	0.095	0.181	0.086	-0.749
31	Electronics	7.968	8.894	1.895	0.601	-0.007	0.220	0.227	-0.966
33	Precision instruments	5.247	1.792	2.102	0.939	-0.199	0.256	0.455	-1.680
34	Transport machines	6.599	4.696	1.971	0.859	-0.046	0.318	0.364	-2.362
36	Furniture	1.476	3.179	2.076	0.874	0.087	0.268	0.180	-1.706
45	Construction Section F	14.916	5.233	1.928	0.630	-0.054	0.218	0.272	-0.982
51	Wholesale	3.483	2.255	2.050	0.962	-0.111	0.315	0.426	-2.612
52	Retail	1.474	0.701	2.744	1.760	-0.569	0.198	0.767	-2.028
55	Hotel and restaurants	11.086	3.595	1.974	0.707	-0.087	0.229	0.316	-1.131
60	Transport Section	2.864	1.141	3.837	1.313	-0.325	0.078	0.403	-0.392
72	IT	1.039	8.409	2.179	0.349	0.121	0.100	-0.021	-0.241
	Average	5.379	4.021	2.166	0.822	-0.054	0.217	0.272	-1.268

Calibration of model for Colombia with marginal cost parameter $\theta = 0.75$. Data: World Bank Enterprise Surveys 2017, World Bank Financial Development Indicators. Note that the estimates of σ and β are unchanged compared to the baseline specification in Table 1.

Table D4: Robustness check - quantification of model with sector-specific Pareto shape parameters

Code	Sector	ξ	σ	α	β	f_l/f_h	b	Price	TFPR	TFPQ	Welfare
17	Textiles	1.840	1.443	8.104	4.176	1.950	0.562	-0.050	0.180	0.230	-0.702
19	Leather	2.530	1.459	13.090	3.811	1.947	0.556	-0.072	0.174	0.246	-0.673
20	Wood	1.650	1.330	4.379	11.974	1.913	0.629	0.036	0.235	0.199	-1.089
22	Publishing, printing	2.460	1.414	11.624	1.721	2.201	0.794	-0.225	0.171	0.397	-0.797
24	Chemicals	1.890	1.278	0.848	2.874	2.199	0.852	0.240	0.228	-0.012	-1.248
25	Plastics and rubber	2.700	1.202	0.931	1.740	2.190	1.044	0.130	0.268	0.138	-2.026
26	Non-metal. mineral prod.	4.110	1.235	2.447	3.004	2.025	0.858	-0.006	0.273	0.279	-1.745
28	Fabricated metal products	3.480	1.375	1.091	3.542	2.145	0.721	0.171	0.192	0.021	-0.861
29	Machinery and equipment	3.210	1.406	1.258	3.830	2.112	0.661	0.135	0.181	0.047	-0.754
31	Electronics	2.340	1.364	6.916	8.894	1.898	0.600	0.000	0.220	0.219	-0.962
34	Transport machines	3.690	1.186	5.728	4.696	1.970	0.860	-0.035	0.318	0.353	-2.365
36	Furniture	3.040	1.235	1.281	3.179	2.075	0.874	0.134	0.268	0.134	-1.707
	Average	2.745	1.327	4.808	4.453	2.052	0.751	0.038	0.226	0.188	-1.244

Calibration of model for Colombia with sector-specific Pareto shape parameters. Source: Crozet and Koenig (2010), Table 3. Data: World Bank Enterprise Surveys 2017, World Bank Financial Development Indicators. Note that the estimates of σ, α and β are unchanged compared to the baseline specification in Table 1.

Table D5: Robustness checks: alternative variable trade costs

Code	Sector	f_l/f_h	b	Price	TFPR	TFPQ	Welfare
15	Food	2.239	0.967	-0.005	0.257	0.262	-1.737
17	Textiles	2.068	0.565	-0.051	0.181	0.232	-0.710
18	Garments	2.037	0.585	0.010	0.199	0.189	-0.819
19	Leather	2.075	0.556	-0.072	0.175	0.246	-0.674
20	Wood	1.988	0.634	0.036	0.236	0.200	-1.108
22	Publishing, printing	2.353	0.795	-0.226	0.171	0.397	-0.799
24	Chemicals	2.260	0.876	0.253	0.231	-0.022	-1.315
25	Plastics and rubber	2.255	1.047	0.131	0.268	0.137	-2.038
26	Non-metal. mineral prod.	2.097	0.855	-0.006	0.272	0.278	-1.734
28	Fabricated metal products	2.282	0.715	0.169	0.191	0.022	-0.848
29	Machinery and equipment	2.249	0.659	0.134	0.181	0.047	-0.749
31	Electronics	1.988	0.601	0.000	0.220	0.220	-0.966
33	Precision instruments	2.180	0.939	-0.185	0.256	0.441	-1.680
34	Transport machines	2.021	0.859	-0.035	0.318	0.353	-2.362
36	Furniture	2.147	0.873	0.134	0.267	0.134	-1.706
45	Construction Section F	2.024	0.630	-0.050	0.218	0.268	-0.982
51	Wholesale	2.100	0.962	-0.090	0.315	0.405	-2.612
52	Retail	2.854	1.760	-0.505	0.198	0.703	-2.028
55	Hotel and restaurants	2.066	0.707	-0.081	0.229	0.310	-1.131
60	Transport Section	4.502	1.312	-0.297	0.078	0.375	-0.392
72	IT	2.402	0.348	0.150	0.100	-0.050	-0.240
	Average	2.295	0.821	-0.028	0.217	0.245	-1.268

Calibration of model for Colombia with variable trade costs $\tau = 1.3$. Data: World Bank Enterprise Surveys 2017, World Bank Financial Development Indicators. Note that the estimates of σ, α, and β are unchanged compared to the baseline specification in Table 1.

Table D6: Robustness check: differences in external finance across sectors

Code	Sector	credit/ sales	b	Price	TFPR	TFPQ	Welfare
15	Food	0.422	1.290	-0.006	0.273	0.279	-1.997
17	Textiles	0.661	0.052	-0.006	0.030	0.036	-0.090
18	Garments	0.364	1.152	0.015	0.247	0.233	-1.196
19	Leather	0.473	0.550	-0.071	0.174	0.245	-0.670
20	Wood	0.299	1.689	0.059	0.306	0.246	-1.803
22	Publishing, printing	0.362	1.842	-0.331	0.185	0.516	-1.172
24	Chemicals	0.393	1.434	0.323	0.253	-0.070	-1.681
25	Plastics and rubber	0.547	0.670	0.102	0.231	0.129	-1.582
26	Non-metal. mineral prod.	0.247	3.347	-0.010	0.293	0.303	-2.916
28	Fabricated metal products	0.374	1.405	0.241	0.220	-0.022	-1.213
29	Machinery and equipment	0.355	1.500	0.207	0.214	0.007	-1.159
31	Electronics	0.265	2.061	0.001	0.287	0.286	-1.741
33	Precision instruments	0.535	0.640	-0.149	0.222	0.371	-1.351
34	Transport machines	0.602	0.425	-0.023	0.221	0.244	-1.521
36	Furniture	0.416	1.189	0.157	0.291	0.134	-1.996
51	Wholesale	0.740	0.168	-0.026	0.108	0.134	-0.751
	Average	0.441	1.213	0.030	0.222	0.192	-1.427

Calibration of model for Colombia with sector-specific measures of external finance. Data: World Bank Enterprise Surveys 2017, World Bank Financial Development Indicators. Credit/sales is computed as the sum of the shares of working capital and of investments that are financed by external sources, divided by firm sales. Note that the estimates of σ, α, β and f_l/f_h are unchanged compared to the baseline specification in Table 1. Due to data availability, results in Table D4 are reported for only 12 sectors.

Table D7: Additional estimation results for Peru, 2016

Sector	labor/ sales	qual./ sales	proc./ sales	share export	σ	α	β	f_l/f_h	b	Price	TFPR	TFPQ	Welfare
Food	0.211	0.016	0.084	0.377	1.268	2.834	2.524	2.060	1.087	-0.061	0.267	0.329	-1.671
Textiles	0.188	0.029	0.051	0.583	1.231	1.398	3.689	2.034	1.081	0.146	0.294	0.147	-1.972
Garments	0.256	0.047	0.052	0.459	1.344	1.171	4.916	2.052	0.924	0.212	0.231	0.019	-1.148
Leather	0.252	0.016	0.092	0.143	1.337	3.443	2.728	2.068	0.988	-0.068	0.234	0.302	-1.242
Wood	0.053	0.004	0.038	0.333	1.055	3.041	1.402	2.036	1.340	-0.261	0.461	0.721	-9.851
Publishing, printing	0.273	0.006	0.077	0.211	1.376	9.203	3.534	1.977	0.862	-0.091	0.227	0.318	-1.081
Chemicals	0.178	0.018	0.048	0.395	1.216	2.191	3.736	2.013	1.074	0.046	0.310	0.265	-2.173
Plastics and rubber	0.165	0.011	0.070	0.548	1.198	3.321	2.360	2.041	1.163	-0.100	0.315	0.415	-2.435
Non-metal. mineral prod.	0.246	0.005	0.013	0.364	1.325	9.895	18.830	1.874	0.794	0.011	0.269	0.258	-1.319
Basic metals	0.169	0.022	0.180	0.667	1.203	1.646	0.936	2.343	1.758	-0.371	0.242	0.612	-2.336
Fabricated metal prod.	0.258	0.022	0.069	0.228	1.348	2.563	3.762	2.025	0.913	0.018	0.235	0.216	-1.175
Machinery, equipment	0.294	0.002	0.030	0.357	1.417	26.423	9.788	1.856	0.700	-0.030	0.226	0.255	-0.940
Electronics	0.149	0.011	0.046	0.500	1.175	2.867	3.204	2.010	1.134	-0.021	0.341	0.362	-2.808
Precision instruments	0.158	0.004	0.008	0.250	1.187	9.337	20.079	1.926	0.992	0.017	0.354	0.337	-2.615
Transport machines	0.204	0.012	0.195	0.333	1.256	3.757	1.045	2.351	1.650	-0.461	0.218	0.680	-1.785
Furniture	0.242	0.010	0.059	0.538	1.319	5.130	4.133	1.966	0.911	-0.042	0.256	0.298	-1.345
Services of motor vehicles	0.071	0.001	0.028	0.024	1.077	12.454	2.507	2.008	1.256	-0.187	0.444	0.631	-7.038
Wholesale	0.147	0.017	0.069	0.081	1.172	1.895	2.123	2.095	1.229	-0.032	0.329	0.360	-2.851
Retail	0.148	0.018	0.061	0.089	1.174	1.754	2.431	2.083	1.201	0.019	0.330	0.311	-2.802
Hotel and restaurants	0.270	0.002	0.054	0.262	1.370	35.163	5.044	1.915	0.808	-0.079	0.239	0.317	-1.115
Transport Section	0.267	0.023	0.158	0.052	1.364	2.520	1.686	2.316	1.209	-0.151	0.194	0.345	-1.102
Average	0.200	0.014	0.071	0.324	1.258	6.762	4.784	2.050	1.099	-0.071	0.286	0.357	-2.419

Calibration of model for Peru; Data: World Bank Enterprise Surveys 2017. Note: The estimation uses the credit to GDP ratio (0.428), and the lending interest rate (16.47%) of Peru in 2016, Source: World Bank Financial Development Indicators.

Table D8: Additional estimation results for Mexico, 2010

Sector	labor/ sales	qual./ sales	proc./ sales	share export	σ	α	β	f_l/f_h	b	Price	TFPR	TFPQ	Welfare
Food	0.208	0.027	0.042	0.205	1.263	1.658	4.926	2.026	3.558	0.207	0.282	0.076	-2.669
Textiles	0.212	0.007	0.045	0.381	1.269	6.369	4.702	1.958	3.213	-0.068	0.303	0.371	-2.636
Garments	0.269	0.012	0.075	0.244	1.368	4.776	3.606	1.994	3.591	-0.088	0.221	0.309	-1.858
Chemicals	0.186	0.028	0.057	0.416	1.228	1.455	3.280	2.052	4.086	0.185	0.277	0.093	-3.107
Plastics & rubber	0.218	0.025	0.090	0.401	1.279	1.903	2.411	2.098	4.941	-0.003	0.208	0.211	-2.503
Non-metal. mineral prod.	0.307	0.043	0.072	0.394	1.443	1.553	4.258	2.057	4.089	0.210	0.168	-0.042	-1.466
Basic metals	0.128	0.003	0.068	0.429	1.147	11.105	1.886	2.041	4.130	-0.370	0.355	0.724	-5.038
Fabricated metal products	0.238	0.021	0.085	0.408	1.312	2.473	2.787	2.060	4.409	-0.034	0.211	0.245	-2.221
Machinery, equipment	0.249	0.040	0.069	0.383	1.331	1.337	3.620	2.081	4.384	0.245	0.202	-0.044	-2.049
Electronics	0.173	0.028	0.016	0.316	1.210	1.349	10.568	1.992	3.257	0.366	0.349	-0.017	-3.399
Other manufacturing	0.242	0.018	0.050	0.274	1.319	2.868	4.841	1.982	3.332	0.051	0.260	0.209	-2.167
Average	0.221	0.023	0.061	0.350	1.288	3.350	4.262	2.031	3.908	0.064	0.258	0.194	-2.647

Calibration of model for Mexico; Data: World Bank Enterprise Surveys 2010. Note: The estimation uses the credit to GDP ratio (0.2265), and the lending interest rate (7.1%) of Mexico in 2009, Source: World Bank Financial Development Indicators.

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