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CREDIT CONSTRAINTS, ENDOGENOUS INNOVATIONS, AND PRICE SETTING IN INTERNATIONAL TRADE*

By Carsten Eckel and Florian Unger

LMU Munich, Germany; CESifo, and CEPR; University of Göttingen, Germany; and CESifo

This article analyzes the role of credit frictions in a trade model where producers differ in their capabilities to conduct process and quality innovations and require external finance for investments. Accounting for cost-based and quality-based sorting of firms in a unified framework allows us to demonstrate that the reactions of prices and commonly used productivity measures do not necessarily reflect welfare implications. Credit frictions lead to distortions through aggravated access to finance and endogenous price adjustments so that the responses of quantity-based and revenue-based productivity differ substantially. In counterfactual scenarios, we show that these differential effects are quantitatively important.

1. Introduction

External credit plays a crucial role in financing 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). Consequently, this negatively affects innovation activity and market participation, especially for smaller firms. Moreover, credit frictions significantly affect 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 a firm's decision to innovate as it does not only affect market participation but also productivity and the consumer prices of goods traded. These changes in prices and productivity in response to credit constraints are perceived as important determinants of welfare and have been increasingly receiving attention in the literature.

In this article, 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. The second type is quality innovations that allow firms to offer products of better quality at higher prices. Existing studies typically focus on only one of the two dimensions regarding how credit frictions affect innovation choices, treating either productivity

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

or quality as exogenous. We demonstrate 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. These firm-specific capabilities reduce the fixed costs required for investing in process and quality innovations. Depending on their capabilities, firms choose different investment levels and prices. Process innovations are improvements in technological know-how or production methods that decrease marginal costs and hence increase the cost-based productivity of a firm for any given quality level. Quality innovations not only 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]

We analyze the implications of higher credit costs and aggravated access to finance through the lens of this model. In this regard, the results of our analysis contribute to a better understanding of the relation between credit frictions and prices depending on the nature of the financial shock. In particular, the effects of credit constraints depend on the scope for vertical product differentiation, which is defined as the ratio of outlays for quality innovations to outlays for process innovations. This measure is determined by technological parameters of the investment cost functions and is closely related to sectoral proxies of quality differentiation, such as the ratio of R&D to sales (see Kugler and 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 toward quality innovations, which results in higher prices. In this case, a positive effect of credit constraints on prices and a positive relation between firm size and prices can occur simultaneously.

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

Our results indicate that whether welfare and price effects are positively or negatively correlated depends on the scope for vertical product differentiation as well. Hence, we relate to recent studies that infer welfare implications from firm-level responses of prices and markups in the context of trade shocks (Behrens et al., 2014; Blaum et al., 2018; Fan et al., 2020). We

[2] Other models that introduce imperfect capital markets based on moral hazard are Antràs and Caballero (2009), von Ehrlich and Seidel (2015), Egger and Keuschnigg (2015), as well as Irlacher and Unger (2018).

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

contribute to this literature by showing that credit frictions distort the relationship between firm-level prices and welfare through the extensive margin.[4]

Furthermore, accounting for endogenous innovations also has important implications for the interpretation of empirical studies that consider productivity effects and typically focus on revenue-based measures (e.g., Forlani et al., 2022; 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; in return, this raises average productivity, which is evident via either a revenue-based (TFPR) or quantity-based (TFPQ) measure of total factor productivity (TFP). Stronger credit frictions induce adjustments in innovations and prices leading to differential responses of these productivity measures that can even move in opposite directions. If the scope for vertical product differentiation is large, positive price effects lower the reaction of TFPQ compared to TFPR.

These differential responses highlight that quantifying the implications of credit frictions is crucial to evaluate the role of endogenous innovations in our framework. Hence, we calibrate our model to match sectoral characteristics related to innovation, exporting and financial development for Columbia in 2016. We quantify the effects of stronger credit constraints and compare them to the ones of three counterfactual scenarios that capture existing classes of models in the literature. These are nested as special cases in our framework and include scenarios (i) without endogenous innovations, (ii) with only process innovations, and (iii) with only quality innovations. In all four variants, a credit shock that aggravates access to external finance leads to increases in average TFPR due to the 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 the exit of the 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 nine 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 demonstrates that the direction and magnitude of price reactions differ substantially depending on the scope for vertical product differentiation across sectors. Only the model variant without innovations exhibits a strong positive correlation between the reaction of prices and welfare to credit frictions. We further highlight that accounting for endogenous adjustments of innovations increases the magnitude of welfare losses from credit constraints by 45% compared to the benchmark model without endogenous innovations.

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. Although the authors do not consider the selection effects of firms, allowing for fixed costs implies that financial development influences TFP through adjustments on the extensive margin (Buera et al., 2011; Midrigan and Xu, 2014). The literature on trade and finance highlights negative effects of credit constraints on firm-level exports and the probability of exporting

[4] By considering firm heterogeneity in foreign input sourcing, Blaum et al. (2018) analyze gains from input trade and effects on firm-level prices. Fan et al. (2020) stress that accounting for endogenous quality heterogeneity is crucial for the responses of welfare and prices with respect to tariff shocks. Behrens et al. (2014) show that trade integration leads to changes of firm-level markups ambiguous to welfare responses. Our model features constant markups, whereas Altomonte et al. (2021) show that firm-level heterogeneity in credit frictions explains part of the dispersion of prices and markups.

(Berman and Héricourt, 2010; Minetti and Zhu, 2011; Muûls, 2015). If firms have to finance fixed export costs (Manova, 2013; Chaney, 2016), credit frictions do not affect prices directly but aggravate the selection of lower productivity firms into foreign markets and thus change average marginal costs, as well as average prices, of participating firms. If external financing is related to variable export costs, then credit constraints positively affect prices (Manova, 2013; Feenstra et al., 2014). These models predict a negative correlation between firm size and prices (Roberts and Supina, 1996; Foster et al., 2008) and do not capture that innovation choices react endogenously to financial shocks.[5]

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

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

Whereas we focus on the implications of credit frictions in the presence of innovations, Berthou et al. (2020) showcase that the effects of trade on welfare and productivity are not monotonic when misallocations across firms are considered. The model's implications are also related to studies that estimate the importance of both cost-based and quality-based determinants for firm-level success in export markets without considering credit frictions (Hottman et al., 2016; Roberts et al., 2017; Aw and Lee, 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

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

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

use of TFPQ allows to measure export-related efficiency gains. Forlani et al. (2022) demonstrate that heterogeneity in markups and demand shocks is as important as differences in productivity to explain firm size, whereas demand factors are an important determinant of export status and TFPR. These studies typically do not take into account the impact of credit frictions on innovation choices that influence cost and quality components of firm performance. Whereas we focus on symmetric countries, Antràs and Caballero (2009) determine via a two-factor, two-sector model that trade and capital mobility are complements in less financially developed economies.

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

2. SETUP OF THE MODEL

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

2.1. *Consumers and Technology.* Preferences of a representative consumer in one country are characterized by a constant elasticity of substitution (CES) utility function over a continuum of differentiated varieties, $X = [\int_{i\in\Omega}(q_i x_i)^{\frac{\sigma-1}{\sigma}} di]^{\frac{\sigma}{\sigma-1}}$, where $i \in \Omega$ denotes the variety, $\sigma > 1$ is the elasticity of substitution, and q_i stands for the quality of a product.[7] The demand for one differentiated variety i increases in the quality level and decreases in the price, $x_i = q_i^{\sigma-1} X(p_i/P)^{-\sigma}$, where the quality-adjusted price index is defined as $P = [\int_{i\in\Omega}(p_i/q_i)^{1-\sigma} di]^{\frac{1}{1-\sigma}}$. Product quality q_i is endogenously chosen by producers and shifts demand outward for any given price. In addition, firms decide on the level of process innovations.

The differentiated sector of the economy is characterized by monopolistic competition. Each active firm manufactures one differentiated variety i and faces three different types of costs: (i) outlays for process innovations and quality innovations, (ii) marginal production costs that are affected by the choices of innovation, and (iii) fixed costs of production. For notational simplicity, we neglect the index i for firm-variables throughout the article but rather denote the export status of a firm by $j \in \{h, l\}$, where $j = h$ stands for nonexporters, 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:

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

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

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

that reduce production costs. Note that the cost functions in Equation (1) can be interpreted as production functions for quality and processes, where $1/\alpha$ and $1/\beta$ reflect the elasticities of quality and processes to innovation outlays.[8] Low values of α and β imply that one additional unit of investment spending is very effective.

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

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

The benefit of process innovations e_j is a reduction of marginal production costs. Quality innovations q_j increase demand for one variety 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 one unit to arrive. As a third component, we assume that exporters face higher fixed costs of production than nonexporters, 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 (1). The decision problem of a single firm consists of four stages:

1. **Entry stage.** A potential producer of a differentiated variety decides to enter the market and pays a fixed entry cost f_e. After entry, the firm draws both investment capabilities φ and κ from a joint probability distribution $g(\varphi, \kappa)$.[10]
2. **Financial contracting and investment.** Producers choose the optimal levels of process and quality innovations and sign a contract with an outside investor to cover the investment costs. Optimal prices are set.
3. **Moral hazard.** After financial contracting, the agent in the firm chooses to conduct the project diligently or misbehave and reap a nonverifiable 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

[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 endogenize the quality choice of firms by assuming a positive relation between output quality and marginal costs, which is often modeled by an input choice. See, for example, Kugler and Verhoogen (2012) and Johnson (2012).

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

[11] In a dynamic model of heterogeneous firms and innovation, Impullitti and Licandro (2018) demonstrate that endogenous productivity growth increases gains from trade through selection of firms. Allowing for dynamics in a

Subsection 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, whereas 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:

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

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

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

where $r > 1$ captures the gross borrowing rate that we treat as fixed. This assumption is primarily taken for exposition reasons to highlight the main implications of the framework most clearly. One can think that the borrowing rate is 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 highlight in Section 4 that the key implications of our model remain valid if endogenous adjustments of the interest rate are taken into account. We further assume perfect competition in the financial sector such that both the budget constraint (3) and the investor's participation constraint (4) hold with equality.

We assume that the probability of success depends on a project choice of the firm, which is nonverifiable 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, implying that profits realize with high success probability λ. On the other hand, if the agent chooses to misbehave, the probability of success is zero, but the borrower can reap a private benefit $bf_j > 0$, which we denote in terms of fixed production costs.

We follow Holmstrom and Tirole (1997) and interpret the private benefit as opportunity costs from managing the project diligently. The agent faces incentives to implement the project in a more pleasant way or 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; hence, it is inversely related to a country's financial development (Antràs et al., 2009). Intuitively, private benefits in case of shirking are proportional to fixed production costs, which are part of the total credit amount. This assumption enhances tractability of our model as it allows us to express the effect of credit frictions relative to other determinants of export success, such as trade costs. All our results remain

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 the Online Appendix, we show that the main results of our model remain valid if we assume that fixed entry costs have to be financed by external credit as well.

qualitatively valid if we assume that the private benefit is a constant. In the Online Appendix, we also demonstrate that the key insights of our model hold if the private benefit is related to the total credit amount.[13] Note that realized profits and loan repayments are zero in case of shirking.[14] Hence, to rule out losses from lending, the optimal credit contract has to satisfy the following incentive compatibility constraint:

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

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

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

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

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

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

whereby $\gamma \equiv \alpha\beta + (1-\sigma)[\alpha + (1-\theta)\beta]$, $\Psi_1 \equiv \lambda^{\frac{\alpha}{\gamma}} (\frac{1-\theta}{\alpha})^{\frac{(\sigma-1)(1-\theta)}{\gamma}} \beta^{-\frac{\alpha+(1-\theta)(1-\sigma)}{\gamma}}$, and $\Psi_2 \equiv \lambda^{\frac{\beta}{\gamma}} (\frac{1-\theta}{\alpha})^{\frac{\beta+1-\sigma}{\gamma}} \beta^{\frac{1-\sigma}{\gamma}}$. The terms $A_h \equiv XP^{\sigma}(\frac{\sigma-1}{\sigma})^{\sigma}$, $A_l \equiv (1+\tau^{1-\sigma})A_h$ capture market characteristics for nonexporters 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.[16] As exporters spread investment costs across both markets, they face larger incentives to engage in quality and process innovations, $(A_l > A_h)$, whereas iceberg transportation costs τ and the borrowing rate r reduce investment activity. Note that the market variables A_j cannot be affected by a single firm but will be endogenously determined in the general equilibrium analysis of Section 3.

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

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

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

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

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

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

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

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

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

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

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

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

and $p_l^*(\varphi,\kappa) = \tau p_l(\varphi,\kappa)$ stands for the foreign price of exporters. The pricing rule captures two opposing effects of investment behavior. A higher level of process innovations enhances production efficiency, whereas quality innovations increase marginal costs according to Equation (2). Consequently, the optimal price decreases in the cost-based capability φ but increases in the quality-based capability κ.[19] Hence, the setup with two innovation choices captures both a negative relation between prices and firm size based on cost-based sorting à la Melitz (2003) and a positive correlation between prices and firm size as suggested by the recent quality and trade literature (e.g., Kugler and Verhoogen, 2012).

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

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

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

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

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 is simplified to $1/\sigma$ as in Melitz (2003). From Equations (10)–(13), it follows that firms with the same z charge the same quality-adjusted price and earn the same revenues as well as profits, but they 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.

[18] Similar to our setting, Hallak and Sivadasan (2013) summarize a firm's cost-based and quality-based capabilities 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.

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

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 are hence determined by the "combined capability" of a firm:[20]

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

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

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

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 is only determined by exogenous parameters of the investment cost functions. Increases in α and θ make quality innovations less effective and reduce the relative expenditures for this investment type. Conversely, the ratio increases in β, which changes investment in favor of product upgrades.[22] In the following analysis, we demonstrate 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. To ensure diligent behavior according to the incentive compatibility constraint (5), the financial sector grants credit only to those firms that have sufficiently high profits. Note that profits in Equation (13) are a function of the combined capability z. Hence, the binding financial constraint (5) determines a cutoff level of combined capability for (non)exporters that is necessary to obtain external finance:

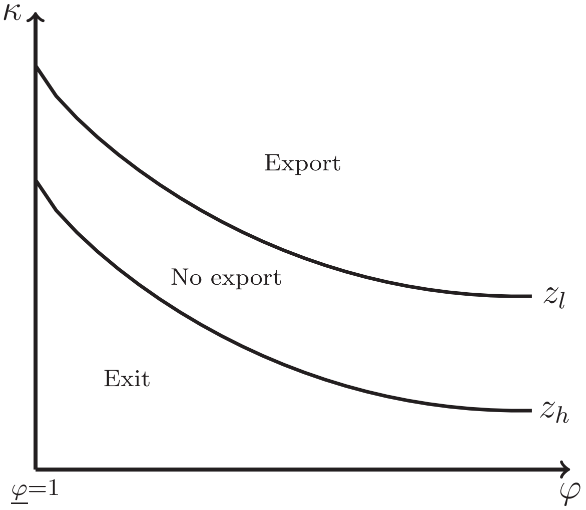
$$\text{(16)} \qquad s_j(z_j) = \frac{\alpha\beta\sigma}{\gamma}\frac{r+b}{\lambda}f_j.$$

Firms with $z > z_j$ are financially unconstrained and are active as (non)exporters. If the private benefit b is equal to zero, financial frictions disappear, and Equation (16) collapses to a zero-profit condition. Whenever the private benefit is positive ($b > 0$), moral hazard prevents external financing of profitable firms with low combined capability $z < z_j$. Similar to Melitz (2003), we impose a condition that fixed export costs f_l and variable trade costs τ are sufficiently high, $f_l/f_h(1+\tau^{1-\sigma})^{\frac{-\alpha\beta}{\gamma}} > 1$, such that the most capable firms with $z \geq z_l$ export.

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

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

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



NOTES: 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.

FIGURE 1

SELECTION PATTERN IN THE OPEN ECONOMY

Firms in the middle range of the (combined) capability distribution ($z_h \leq z < z_l$) sell only domestically, whereas the least efficient firms ($z < z_h$) have no access to external finance and exit.[23] Figure 1 depicts the selection pattern of firms in the two-dimensional capability space.

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

Marginal firms, characterized by the cutoff levels of combined capability z_j, just meet incentive compatibility (5) and are indifferent between diligent behavior and shirking, such that profits are equal to the probability-weighted private benefit: $\pi(z_j) = bf_j/\lambda$. These selection effects depend on the scope for vertical product differentiation. The elasticity of the marginal-access curve in the two-dimensional capability space is the negative inverse of Equation (15): $d\ln\kappa/d\ln\varphi = -\alpha/(\beta(1-\theta))$. Hence, sectors with higher quality differentiation are characterized by flatter marginal-access curves in Figure 1. In this case, access to finance is mainly determined by a minimum requirement on the quality-based capability, and our model is closely related to single-attribute frameworks that focus on quality sorting (e.g., Baldwin and Harrigan, 2011; Kugler and Verhoogen, 2012). From Equation (11), it follows that the optimal price depends on the relative importance of the two capabilities φ and κ. If the scope for vertical product differentiation (15) is high, then larger firms with higher-quality-based capability κ invest more in quality upgrades, resulting in higher prices consistent with empirical evidence (e.g., Manova and Zhang, 2012). In contrast, if the scope for vertical differentiation is low, marginal-access curves become steeper and the model resembles the type of economy with cost-based sorting as in Melitz (2003). In sectors with low-quality differentiation,

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

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

empirical studies point to a negative relation of firm size with unit values (Foster et al., 2008; Roberts and Supina, 1996). 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

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

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

where $\chi_s = \iint_{(\varphi,\kappa)\in D} g(\varphi,\kappa)d\varphi d\kappa$ is the probability of success, D denotes the set of all active firms in equilibrium, and D_j, with $j \in h, l$, are the regions of nonexporters and exporters, respectively, as depicted in Figure 1 (see the Online Appendix for technical details). The share of (non)exporters is defined as $\psi_j = \chi_j/\chi_s$, and $\mu_s(\varphi,\kappa) = g(\varphi,\kappa)/\chi_s$ denotes the probability of drawing a particular combination of capabilities, conditional on success. We abstract from external financing of fixed entry costs, such that expected profits are used to cover entry costs. In the Online Appendix, we show that relaxing this assumption generates additional effects without changing the main implications of our framework.[26]

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

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

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

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

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

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

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

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

We obtain an explicit solution for the entry cutoff z_h by assuming that firms draw both innovation capabilities φ and κ from Pareto distributions with positive support over $[1, \infty] \times [1, \infty]$. To keep our model tractable, we further assume that the two capability draws are independently distributed. Relaxing this assumption would generate additional insights on the relative importance of cost-based and quality-based determinants for firm performance. If there is a positive correlation between the draws, then process and quality innovations are complements. In this case, firms with the same combined capability are less heterogeneous in terms of price setting and investment behavior. A negative correlation between the two capability draws implies that the heterogeneity between firms with the same size increases. In Figure 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 the following: $g(\varphi, \kappa) = g_\varphi(\varphi) g_\kappa(\kappa)$ with $g_\kappa(\kappa) = \xi \kappa^{-\xi-1}$ and $g_\varphi(\varphi) = \vartheta \varphi^{-\vartheta-1}$, where ξ and ϑ are the shape parameters of the Pareto distributions. To achieve a well-defined equilibrium, we assume that the shape parameters are sufficiently large. We provide the technical details of the model's solution with Pareto-distributed draws in the Online Appendix.

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

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

4. EFFECTS OF CREDIT FRICTIONS

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

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

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

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

PROOF. See Appendix A.2. □

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

[28] Antràs and Caballero (2009) determine 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.

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

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

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

PROPOSITION 2. *An increase in credit frictions (higher b) reduces welfare unambiguously:* $d\ln X/d\ln b < 0$. *Prices, however, are NOT a unique indicator of welfare. Depending on the scope for quality differentiation* ($\alpha \lesseqgtr \beta\theta$)*, prices will rise or fall in response to an increase in credit frictions* ($d\ln p_j/d\ln b \gtreqless 0$)*, leading to either a negative or a positive correlation between prices and welfare* ($\frac{d\ln X}{d\ln b}/\frac{d\ln p_h}{d\ln b} \lesseqgtr 0$)*.*

PROOF. See Appendix A.2. □

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

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

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

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

The welfare effect of credit frictions is obtained after adjusting the price response by a correction term that depends on the scope for vertical product differentiation. If the scope for quality differentiation is relatively high ($\alpha < \beta\theta$), then stronger credit frictions raise prices. In this

[29] Credit frictions also negatively affect the decision to export (Berman and Héricourt, 2010; Minetti and Zhu, 2011). During the financial crisis 2008–9, the number of exported varieties declined, which can be explained by a credit shock that aggravated access to finance (Unger, 2021).

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

case, the responses of prices and welfare are negatively correlated. If quality differentiation is low ($\alpha > \beta\theta$), credit frictions reduce prices; consequently, prices and welfare are positively correlated. We further investigate the relation between prices and welfare in our counterfactual analysis presented in Section 5.

4.3. *Productivity Effects.* We further demonstrate how differential effects of credit frictions on investments and prices influence firm-level productivity. First, we define a quantity-based productivity measure (TFPQ) as the ratio of output relative to total factor input:

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

where $l_j(z) = (\sigma - 1)/\sigma s_j(z)$ denotes variable production costs, and $r/\lambda d_j(z)$ represents capital costs for fixed and endogenous innovations. Note that capital costs are weighted by $1/\lambda$ as investors take into account that credit repayment occurs with a probability smaller than one and hence demand a larger return to satisfy the participation constraint in Equation (4). The expression in Equation (21) is our measure of physical efficiency. In many empirical studies, physical output data at the firm level are not directly observable or difficult to compare because of different units of measurement. A common approach is the use of revenue-based productivity measures (TFPR) to estimate production functions (Forlani et al., 2022; Garcia-Marin and Voigtländer, 2019). In our model, TFPR is given by revenues over total factor costs, where the wage is normalized to one:

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

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

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

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

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

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

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

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

Proof. See Appendix A.2. □

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

Change in interest rate. In contrast to stronger credit frictions, a higher borrowing rate reduces process and quality innovations of all firms. In addition, there is a rise in the cutoff level, which further lowers innovation activity of surviving producers, as the competitive advantage relative to the marginal firm shrinks (see Appendix A.3 for technical details). Compared to credit frictions, the scope for vertical product differentiation (15) reversely impacts prices in Equation (11). If the scope for vertical product differentiation is low, higher credit costs reduce process innovations relatively more than quality investments, which increases firm-level prices. As a consequence, both TFPQ and TFPR decrease. If the scope for vertical product differentiation in a sector is relatively high ($\alpha < \beta\theta$), then credit costs reduce prices and TFPR due to a relatively stronger decrease in quality innovations. This price reaction counteracts the direct impact of reduced investments on TFPQ. Hence, the key result from this comparative static analysis is that the relationship between credit conditions, prices, and welfare depends on the nature of the financial shock and the scope for vertical product differentiation.

Endogenous interest rate. As discussed in Section 2, our analysis is based on the assumption of a fixed interest rate. Hence, stronger credit frictions b reduce capital demand due to

[31] Table A.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. In this regard, we extend the model in the Online Appendix by allowing for private benefits proportional to total loan size.

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

On the importance of extensive margin adjustments. Finally, we want to discuss the relevance of the extensive margin adjustments for our results. For this purpose, we hold the mass of active firms and their modes of operations fixed and analyze how our results are affected by this variation of our model. The extensive margin has multiple dimensions in our framework: free entry, determining the mass of firms M, and selection into domestic production and exporting, captured by the two cutoffs z_h and z_l. Together, these three parameters determine average capability $\tilde{z} = \tilde{z}(M, z_h, z_l)$. In this section, we assume that $\tilde{z}$ is fixed so that all adjustments are entirely at the intensive margin.

Since welfare is a function of the quality-adjusted price index $P^{1-\sigma} = \int_{i\in\Omega}(p_i/q_i)^{1-\sigma}di$ (see Subsection 2.1), we have to take a closer look at how effective prices are set. If the extensive margin is fixed, the price index P only changes with individual effective prices p_i/q_i. Given Equations (10) and (11), effective prices are set as a constant markup over effective marginal costs c_j^e, which, in turn, depend on r/A_j. Furthermore, A_j can be expressed as $A_j(r, \tilde{z}) = \Psi_4 \tilde{z}^{\frac{1-\sigma}{\alpha\beta}} r^{(1-\frac{\gamma}{\alpha\beta})}$, where $\Psi_4^{\alpha\beta/\gamma} \equiv \frac{\sigma-1}{\sigma}(\beta^\alpha(\frac{\alpha}{1-\theta})^{\beta(1-\theta)})^{(\sigma-1)/\gamma} I\lambda^{-\alpha\beta/\gamma}(1 + \mathbb{I}_{j=l}\tau^{1-\sigma})^{\alpha\beta/\gamma}$. Thus, all terms depending on effective prices can be written as functions of r and $\tilde{z}$: $p_j/q_j = p_j/q_j(r, \tilde{z})$, $q_j = q_j(r, \tilde{z})$, $e_j = e_j(r, \tilde{z})$, and, ultimately, $P = P(r, \tilde{z})$.

Given $P = P(r, \tilde{z})$, credit frictions (changes in b) affect welfare only through changes in the average combined capability $\tilde{z}$, which is driven by adjustments at the extensive margins. If $\tilde{z}$ was fixed, changes in b would have no effect on P and welfare. This is intuitive because the private benefit b essentially constitutes an outside option to producing that only affects the decision of whether to produce or not to produce. As Equations (5) and (16) demonstrate, this acts as an increase in the effective fixed costs [from rf to $(r+b)f$]. Hence, changes in b affect the equilibrium only through extensive margin adjustments.

This is different for changes in the interest rate r. The interest rate also has a fixed cost component since fixed costs are financed through external credit and need to be repaid with interest. However, firms also need to borrow money for their expenditures on innovation (see Equation (3)). Hence, changes in r also have a direct effect on the equilibrium through changes in the innovative behavior of firms. This direct effect implies that welfare would be affected by changes in r even if $\tilde{z}$ was kept constant.

Notably, the result that changes in b affect welfare only through the extensive margin depends crucially on the assumption that private benefits are proportional to fixed production costs only. If private benefits are proportional to the entire loan (including expenditure for innovation), then changes in these benefits b also affect the innovative behavior of firms and thus also have a direct effect on welfare through the intensive margin. This can be seen by Equation (2.2) in the Online Appendix (Section 2.1) where this case is discussed.

5. QUANTITATIVE ANALYSIS OF CREDIT FRICTIONS

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

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

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

which allows us to obtain the implied ratio of fixed export costs to domestic fixed costs.[34] Finally, it follows from Equation (19) that the capital amount relative to sales is given by $K/S = \widetilde{f}/(\lambda\tilde{s}) + (\alpha\beta-\gamma)/(\alpha\beta\sigma r)$. We show in the Online Appendix that Equation (19) can be solved for the private benefit b, which depends negatively on the ratio of credit over sales

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

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

[34] Additional targeting of trade shares by sector would allow to obtain sector-specific estimates of variable trade costs. While this step is important when estimating trade shocks, see, for example, Melitz and Redding (2015), we abstract from it and demonstrate in the robustness checks that our results do hardly change with variation in variable trade costs. The reason is that changes in variable trade costs imply opposite adjustments of fixed export costs to match the share of exporters in Equation (25), whereas the impact of credit frictions depends on the joint size of variable and fixed trade costs.

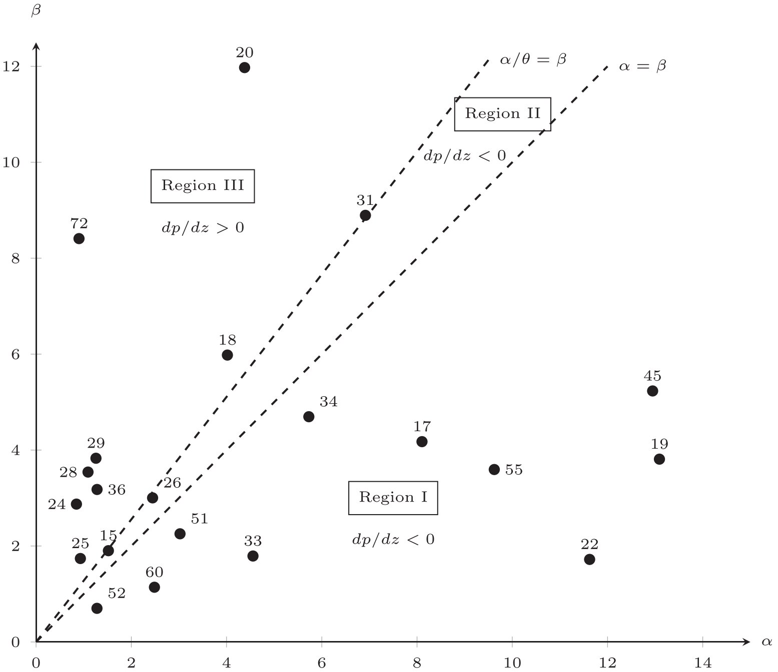
TABLE 1
MATCHED MOMENTS AND PARAMETER ESTIMATES BY SECTOR

		Matched Moments by Sector				Parameter Estimates by Sector				
Sector	Code	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
Nonmetal. 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

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

and is further affected by the exogenous model's parameters as obtained from the previous calibration steps. Intuitively, a larger credit-to-sales ratio reflects better access to finance and hence reduces the degree of credit frictions measured by the parameter b. We use the ratio of private credit to GDP (0.471 for Colombia in 2016, according to the World Bank's Financial Development Indicators) as the empirical counterpart for the credit-to-sales ratio in our model. Although this measure is country-specific, the procedure takes into account heterogeneity in credit demand across sectors captured by differences in investment intensity and relative export costs. This allows us to compute sector-specific values for the private benefit b (we additionally consider differences in access to external finance across sectors in the robustness checks). Table 1 summarizes the targeted moments and the implied parameter values by sector (see the Online Appendix for technical details of the calibration).

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 (Kugler and Verhoogen, 2012; Manova and Zhang, 2012). We calibrate this second category of models by targeting the ratio of expenditures on research and development relative to sales while neglecting process



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	+	−	−	−/+

NOTES: 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, whereas 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 2

EFFECTS OF FINANCIAL SHOCKS DEPENDING ON INVESTMENT PARAMETERS

innovations, such that $\varphi = 1$ for all firms. In contrast, the third counterfactual scenario represents a situation with a very large parameter α, leading to cost-based sorting ($z = \varphi$) with only process innovations that are governed by β. Parameter estimates of the benchmark cases and technical details of the counterfactual scenarios are provided in Part 3 and Table 1 in the Online Appendix.

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

Whereas this illustration only highlights the direction of effects, we now turn to the quantitative importance of the responses. We explore the effects of a 1% increase in credit frictions b. Table 2 reports the corresponding elasticities of prices, welfare, and average productivity measures as summarized in Propositions 2 and 3.[36] In case of a model without endogenous 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 nine out of 21 sectors where quality differentiation is high.

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

Discussion of results. The quantification of the model highlights 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

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

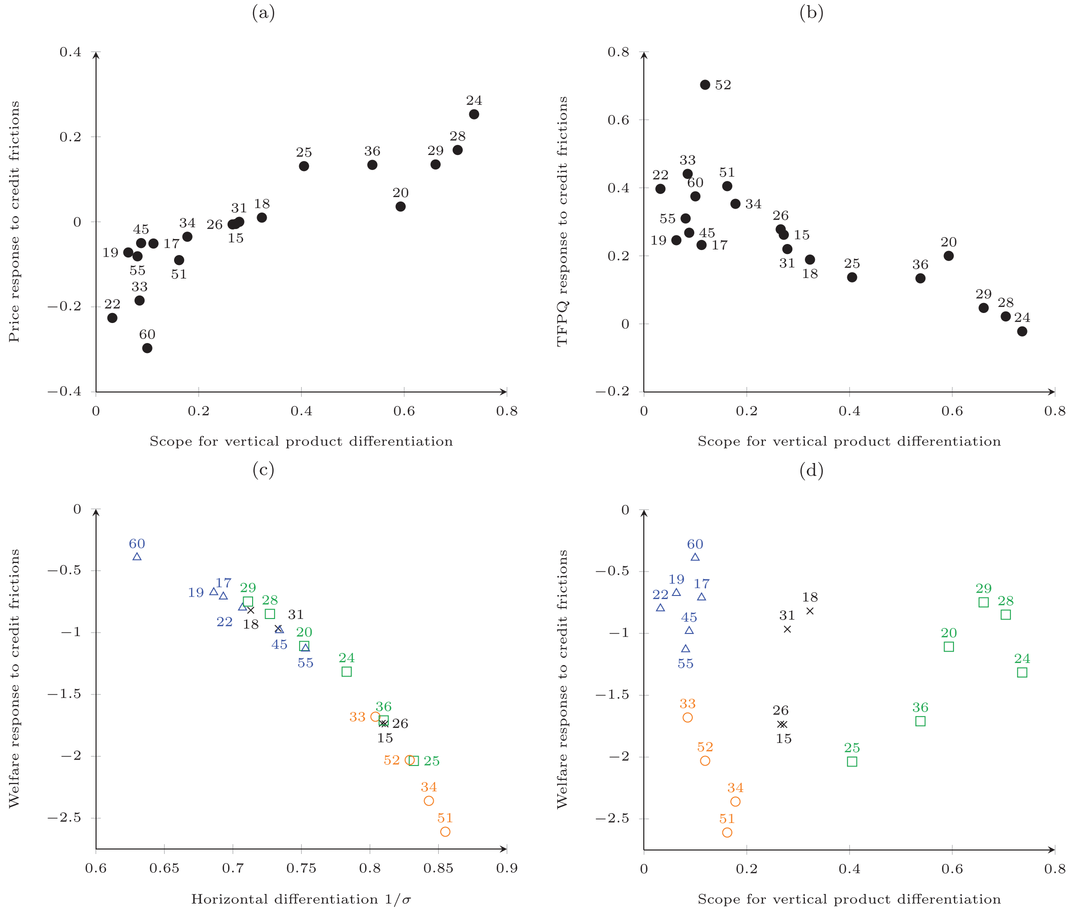
[36] The explicit solutions of the elasticities of prices, welfare and productivity are shown in Equations (A.8), (A.10), and (A.13) in Appendix A.2.

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
Nonmetal. 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
Nonmetal. 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

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



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

FIGURE 3

RELATION OF SCOPE FOR VERTICAL PRODUCT DIFFERENTIATION WITH PRICE ELASTICITY TO CREDIT FRICTIONS (PANEL A), ELASTICITY OF TFPQ TO CREDIT FRICTIONS (B)

credit frictions driven by lower product variety (see Proposition 2).[37] Note that the welfare response according to Equation (20) can be interpreted as a change in the inverse quality-adjusted price index for each sector. Prices and welfare responses move in the same direction if quality innovations are not taken into account. However, in our framework with two types of innovation, a correction term following Equation (20) is required to infer welfare implications from price reactions. This correction term reflects the difference between price and welfare effects in Panel D of Table 2.

Only in the model variant without innovations, the responses of prices and welfare show a strong positive correlation. In contrast, the presence of investments does not allow to infer welfare implications from price reactions as the differential impact depends on the relative

[37] One exception is the IT sector in case of only quality innovations (see Panel C of Table 2), where the negative variety effect captured by the first term in Equation (A.10) is relatively small (−0.375). The efficiency gain (0.390), reflected by the second term in Equation (A.10), outweighs the direct effect leading to a slightly positive welfare response of 0.015.

importance of process and quality adjustments.[38] We highlight this feature in Panels (c) and (d) of Figure 3 by relating the welfare effects across sectors to horizontal and vertical product differentiation. Higher horizontal differentiation (a lower elasticity of substitution σ) implies that consumers care more about product variety, thus resulting in a stronger direct welfare loss. Consequently, Panel (c) shows a positive relation between horizontal differentiation and welfare losses of credit frictions. The role of horizontal differentiation for welfare is especially important in sectors with low scope for vertical product differentiation belonging to Region I in Figure 2. Within this category, sectors with low horizontal differentiation (marked by triangles in Panels (c) and (d) of Figure 3) display relatively smaller welfare changes, whereas sectors with high horizontal differentiation (marked with circles) react with stronger welfare losses to credit frictions. In contrast, for sectors in Region III of Figure 2, welfare effects are reduced with increasing scope for vertical product differentiation (marked by squares in Panels (c) and (d) of Figure 3). This result is driven by the fact that direct welfare losses become larger when quality innovations are subject to more convex investment costs (higher α). Conversely, a larger scope for quality reduces the losses in product variety arising from credit frictions.[39]

The counterfactual analysis highlights that the relationship between productivity, prices, and welfare becomes more complicated than suggested by models that capture either cost-based or quality-based sorting. Hence, inferring welfare implications of financial shocks from the reaction of prices and productivity based on these models leads to inaccurate conclusions about the underlying mechanism if general equilibrium adjustments of innovations are not taken into account. These distortions of prices and productivity measures arising from the interaction of endogenous innovations and firm exit are not considered 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 that 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 to explain productivity differences across countries and sectors. In this regard, we allow for fixed costs and endogenous entry, which leads to additional distortions of prices and productivity measures. Our results suggest that accounting for the importance of process and quality innovations measured by the investment intensity relative to sales is key to determine the effects of credit frictions across sectors (see Figure 3). Building on a trade model where firms differ both in productivity and distortions, Berthou et al. (2020) determine that resource misallocation across firms has ambiguous effects on the gains from trade. Whereas we focus on the effects of credit frictions, the authors find that export and import shocks lead both to aggregate productivity gains, but have differential implications for resource allocation across firms. Evidence shows that export expansion reallocates activity toward more productive firms, especially when market distortions are relevant. This relates to our model where credit frictions distort the entry of low-productivity firms and increase market shares of larger producers through higher innovation activity.[40]

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

[39] Figure A.1 shows that these patterns qualitatively hold in a model with only quality innovations when the ratio of quality innovations to sales is used as a measure for vertical product differentiation.

[40] Berthou et al. (2020) allow for heterogeneity in productivity and distortions that are both firm-specific and drawn from a joint distribution without considering endogenous innovations. Our setting is based on firms that differ in their

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

We additionally consider a lower elasticity of marginal production costs with respect to quality ($\theta = 0.75$, see Table 3 in the Online Appendix). Ceteris paribus, this leads to a positive price effect following Equation (A.8). However, note that we target the scope for vertical product differentiation (15) such that a decrease in θ leads to a larger estimate for α to ensure that the relative importance of quality innovations and process innovations is unchanged. These counteracting effects explain why price reactions tend to be more negative, which increases TFPQ, whereas 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 (see Table 4 in the Online Appendix). Note that this does not affect the values for the elasticity of substitution and the investment cost parameters. Sectors with a larger Pareto shape parameter face slightly stronger welfare losses, whereas the main implications remain unchanged. A more skewed productivity distribution leads to stronger selection effects and hence larger losses in product variety from credit frictions.

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

In the last step, we have used private credit to GDP as a country-level proxy for financial development. Alternatively, we allow for variation in the access to external finance across sectors (see Table 6 in the Online Appendix). The World Bank Enterprise Surveys ask firms to report the shares of working capital and investments that were financed by internal sources, such as retained earnings and external funds, including bank credit. We compute the sum of total production costs (net of labor costs) and investments that is financed by external sources and divide the amount by firm sales. Using the mean value by sector provides a direct proxy for the theoretical counterpart in Equation (19). Sectors with larger credit amount relative to sales have better access to finance, reflected by lower values of the private benefit b.[42] Welfare losses tend to be larger in sectors with higher levels of credit frictions without changing the main implications compared to the baseline specification.

capabilities to invest in processes and quality, and introduces credit frictions that represent an entry barrier for the least productive firms. More generally, one common feature is that distortions drive a wedge between the cutoff level of the least efficient firms and measures of productivity and welfare. In this regard, Foellmi et al. (2021) provide theory and evidence that credit constraints decrease welfare gains from trade by reducing R&D investments of firms.

[41] In Table 5 of the Online Appendix, we show results for variable trade costs $\tau = 1.3$ instead of 1.7.

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

Finally, we quantify the model for Peru in 2016 and Mexico in 2010 (see Tables 7 and 8 in the Online Appendix). For both countries, financial development is lower; hence welfare losses of credit frictions are larger compared to Table 2.[43] Similar to Colombia, the average price response to credit frictions is negative for Peru, which results in a larger (positive) TFPQ reaction compared to TFPR. In contrast, prices increase in response to credit frictions on average across Mexican sectors leading to a smaller reaction of TFPQ.

6. CONCLUSION

This article 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 demonstrates 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, thus increasing the 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 TFPQ compared to TFPR. In a counterfactual analysis, we show that these differential effects are quantitatively important compared to existing classes of models that capture either only one dimension of innovations or no innovations. We highlight that welfare effects can be inferred from price reactions after adjusting for the relative importance of process and quality innovations. Hence, our analysis contributes to an influential literature that analyzes price variation across firms and countries to infer the determinants of export performance and associated welfare effects.

Furthermore, our results convey 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, considering 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 into 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 including heterogeneity in export entry costs. Finally, we rely on a static framework, whereas the 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.

APPENDIX

A.1 *Marginal-Access Condition and Selection Pattern of Firms.* Inserting effective marginal production costs (10) and sales (12) into the marginal-access condition (16) leads

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

to an explicit solution for the cutoff level of combined capability that is necessary to obtain external finance:

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

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

A.2 *Proofs of Propositions.*

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

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

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

$$\text{(A.2)} \qquad \frac{d\ln z_h}{d\ln b} = \frac{\beta(1-\theta)}{\xi}\frac{\Omega b f_h \Delta_z}{\mathrm{E}[\pi]} > 0, \frac{d\ln z_h}{d\ln r} = \frac{\beta(1-\theta)}{\xi}\frac{\Omega r f_h \Delta_z - r\widetilde{f}}{\mathrm{E}[\pi]} > 0.$$

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

$$\text{(A.3)} \qquad e_j = \left(\frac{r}{\lambda}\right)^{\frac{-1}{\beta}} \beta^{-\frac{1}{\beta}} \left(\frac{(r+b)f_j}{\lambda\upsilon}\right)^{\frac{1}{\beta}} z_j^{\frac{1-\sigma}{\beta\gamma}} \varphi^{\frac{\alpha+(1-\theta)(1-\sigma)}{\gamma}} \kappa^{\frac{(\sigma-1)(1-\theta)}{\gamma}},$$

$$\text{(A.4)} \qquad q_j = \left(\frac{r}{\lambda}\right)^{\frac{-1}{\alpha}} \left(\frac{\alpha}{1-\theta}\right)^{\frac{-1}{\alpha}} \left(\frac{(r+b)f_j}{\lambda\upsilon}\right)^{\frac{1}{\alpha}} z_j^{\frac{1-\sigma}{\alpha\gamma}} \kappa^{\frac{\beta+1-\sigma}{\gamma}} \varphi^{\frac{\sigma-1}{\gamma}},$$

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

$$\text{(A.5)} \quad \frac{d\ln e_j}{d\ln b} = \frac{1}{\beta}\frac{d\ln(\lambda\widetilde{s})}{d\ln b} - \frac{\sigma-1}{\beta\gamma}\frac{d\ln z_h}{d\ln b} > 0; \frac{d\ln q_j}{d\ln b} = \frac{1}{\alpha}\frac{d\ln(\lambda\widetilde{s})}{d\ln b} - \frac{\sigma-1}{\alpha\gamma}\frac{d\ln z_h}{d\ln b} > 0.$$

By inserting the derivative of the cutoff level (A.2), we obtain the following effect:

$$\text{(A.6)} \qquad \frac{d\ln e_j}{d\ln b} = \frac{1}{\beta}\frac{b}{r+b}\left(1 - \frac{\beta(\sigma-1)(1-\theta)}{\xi\gamma}\frac{\mathrm{E}[\pi]+r\widetilde{f}}{\mathrm{E}[\pi]}\right),$$

$$\text{(A.7)} \qquad \frac{d\ln q_j}{d\ln b} = \frac{1}{\alpha}\frac{b}{r+b}\left(1 - \frac{\beta(\sigma-1)(1-\theta)}{\xi\gamma}\frac{\mathrm{E}[\pi]+r\widetilde{f}}{\mathrm{E}[\pi]}\right).$$

The investment responses are positive as long as $\frac{\beta(1-\theta)(\sigma-1)}{\xi\gamma}\frac{\mathrm{E}[\pi]+r\tilde{f}}{\mathrm{E}[\pi]}<1$. Note that $\frac{\beta(1-\theta)(\sigma-1)}{\xi\gamma}<1$ (see Condition 1) and $\frac{\partial(\frac{\mathrm{E}[\pi]+r\tilde{f}}{\mathrm{E}[\pi]})}{\partial b}<0$. Hence, the derivatives in Equations (A.6) and (A.7) are positive whenever the private benefit is sufficiently high. The derivatives of the optimal price in Equation (11) can be derived analogously:

$$\text{(A.8)} \qquad \frac{d\ln p_j}{d\ln b}=\frac{\beta\theta-\alpha}{\alpha\beta}\underbrace{\left(\frac{b}{r+b}+\frac{1-\sigma}{\gamma}\frac{d\ln z_j}{d\ln b}\right)}_{>0}.$$

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

$$\text{(A.9)} \qquad X=IP^{-1}=\left(\frac{\sigma-1}{\sigma}I\right)^{\frac{\sigma}{\sigma-1}}\beta^{-\frac{1}{\beta}}\left(\frac{1-\theta}{\alpha}\right)^{\frac{1-\theta}{\alpha}}r^{-\frac{\alpha+\beta(1-\theta)}{\alpha\beta}}\left(\frac{v}{(r+b)f_d}\right)^{\frac{\gamma}{\alpha\beta(\sigma-1)}}z_h^{\frac{1}{\alpha\beta}},$$

where $I=(\lambda+r)L$. We provide more technical details on the derivation of welfare in the Online Appendix. The elasticity of welfare (A.9) with respect to credit frictions is given by:

$$\text{(A.10)} \qquad \frac{d\ln X}{d\ln b}=-\frac{1}{\alpha\beta}\left(\frac{\gamma}{\sigma-1}\frac{b}{r+b}-\underbrace{\frac{d\ln z_h}{d\ln b}}_{>0}\right)<0.$$

We insert the reaction of the cutoff level (A.2) into Equation (A.10), which leads to the following:

$$\text{(A.11)} \qquad \frac{d\ln X}{d\ln b}=-\frac{\gamma}{\alpha\beta(\sigma-1)}\frac{b}{r+b}\left(1-\frac{\beta(1-\theta)(\sigma-1)}{\xi\gamma}\frac{\mathrm{E}[\pi]+r\tilde{f}}{\mathrm{E}[\pi]}\right).$$

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

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

By taking into account the effect of the borrowing rate on the cutoff level z_h in Equation (A.2), we can rewrite the welfare response as follows:

$$\text{(A.12)} \qquad \frac{d\ln X}{d\ln r}=-\frac{\alpha+\beta(1-\theta)}{\alpha\beta}-\frac{\gamma}{\alpha\beta(\sigma-1)}\frac{r}{r+b}+\frac{1-\theta}{\alpha\xi}\frac{\Omega r f_d\Delta_z-r\widetilde{f}}{\mathrm{E}[\pi]},$$

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

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

Note that the left-hand side of the inequality is larger than one under Condition 2, and the right-hand side is smaller than one. Thus, both adjustments at the intensive and extensive margin lead to negative welfare effects.

Proof of Proposition 3. We combine Equations (A.8) and (24) to obtain the effect of credit frictions on quantity-based productivity (TFPQ):

$$\text{(A.13)} \qquad \frac{d\ln\tilde{\Phi}_j^Q}{d\ln b} = \frac{rf_j}{\lambda\tilde{l}_j + r\tilde{d}_j}\frac{b}{r+b} - \frac{\beta\theta-\alpha}{\alpha\beta}\left(\frac{b}{r+b} - \frac{\sigma-1}{\gamma}\frac{d\ln z_j}{d\ln b}\right).$$

By neglecting the last effect of credit frictions on the cutoff level z_j in Equation (A.13), 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:

$$\text{(A.14)} \qquad \frac{\beta\theta-\alpha}{\alpha\beta} > \frac{1}{\frac{\Omega(r+b)}{r\upsilon}\left(1+\frac{1}{\beta}+\frac{1-\theta}{\alpha}\right)+1}.$$

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 consider the effect of credit frictions on z_j, as shown in Equation (A.2), a sufficient condition for a negative effect on TFPQ can be written as follows:

$$\text{(A.15)} \qquad \frac{\beta\theta-\alpha}{\alpha\beta}\left(1-\frac{\beta(1-\theta)(\sigma-1)}{\xi\gamma}\frac{\mathrm{E}[\pi]+r\tilde{f}}{\mathrm{E}[\pi]}\right) > \frac{1}{\frac{\Omega(r+b)}{r\upsilon}\left(1+\frac{1}{\beta}+\frac{1-\theta}{\alpha}\right)+1}.$$

From the proof of Proposition 1 follows that $\frac{\beta(1-\theta)(\sigma-1)}{\xi\gamma}\frac{\mathrm{E}[\pi]+r\tilde{f}}{\mathrm{E}[\pi]} < 1$. Hence, the relative size of α compared to β is still decisive to determine the direction of the effect. However, the left-hand side becomes smaller compared to Equation (A.14) such that lower values of α are required to meet the sufficient condition in Equation (A.15).

A.3 *Effect of Interest Rate on Firm-Level Outcomes.* Analogous to the case of stronger credit frictions in Proposition 1, a higher borrowing rate leads to a reduction in product variety and increases the cutoff level of combined capability: $\frac{d\ln M}{d\ln r} = -\frac{d\ln(\lambda\tilde{s})}{d\ln r} = -\frac{r}{r+b} < 0$, $\frac{d\ln z_h}{d\ln r} > 0$. The impact of credit costs on innovations is as follows:

$$\text{(A.16)} \qquad \begin{aligned} \frac{d\ln e_j}{d\ln r} &= -\frac{1}{\beta}\left(\frac{b}{r+b}+\frac{\sigma-1}{\gamma}\frac{d\ln z_j}{d\ln r}\right) < 0, \\ \frac{d\ln q_j}{d\ln r} &= -\frac{1}{\alpha}\left(\frac{b}{r+b}+\frac{\sigma-1}{\gamma}\frac{d\ln z_j}{d\ln r}\right) < 0. \end{aligned}$$

To obtain Equation (A.16), we take the derivatives of Equations (A.3) and (A.4) with respect to the borrowing rate r. We take into account the change in the cutoff level as shown in Equation (A.2), which leads to the following:

$$\text{(A.17)} \qquad \frac{d\ln e_j}{d\ln r} = -\frac{1}{\beta}\left(\frac{b}{r+b}+\frac{\sigma-1}{\gamma}\frac{\beta(1-\theta)}{\xi}\frac{\Omega r f_d\Delta_z - r\widetilde{f}}{\Omega(r+b)f_d\Delta_z - r\widetilde{f}}\right) < 0.$$

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

$$\text{(A.18)} \qquad \frac{d\ln p_j}{d\ln r} = \frac{\alpha-\beta\theta}{\alpha\beta}\left(\frac{b}{r+b}+\frac{\sigma-1}{\gamma}\frac{d\ln z_j}{d\ln r}\right).$$

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

$$\text{(A.19)} \qquad \frac{d\ln\tilde{\Phi}_j^Q}{d\ln r} = \underbrace{\frac{d\ln\tilde{\Phi}_j^R}{d\ln r}}_{<0} - \frac{d\ln\tilde{p}_j}{d\ln r} \lesseqgtr 0,$$

where the effect of credit costs on TFPR is always negative, $\frac{d\ln\tilde{\Phi}_j^R}{d\ln r} = -\frac{rf_j}{\lambda\tilde{l}_j + r\tilde{d}_j}\frac{b}{r+b} < 0$, and the reaction of prices depends on the scope for vertical product differentiation according to Equation (A.18).

A.4 *Comparison of Results in Partial and General Equilibrium.*

TABLE A.1
FIRM-LEVEL EFFECTS OF FINANCIAL SHOCKS 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		+*	−*	−	+

NOTE: $*$ 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 $\alpha < \beta\theta$.

A.5 *Results of Counterfactual Analysis.*

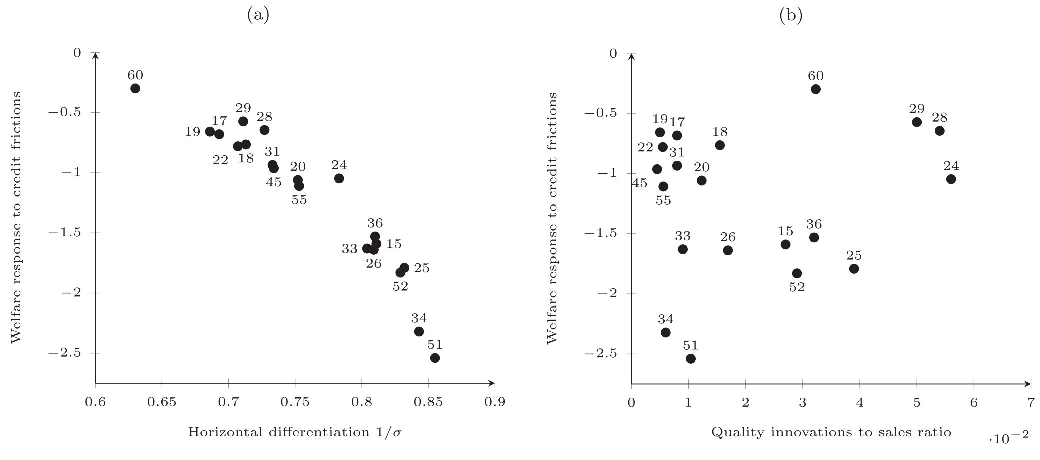


FIGURE A.1

RELATION OF WELFARE RESPONSE TO CREDIT FRICTIONS WITH (A) HORIZONTAL DIFFERENTIATION AND (B) QUALITY DIFFERENTIATION IN MODEL WITH ONLY QUALITY INNOVATIONS

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Table 1: Parameter estimates by sector for benchmark cases
Figure 1: Relation of R&D intensity following Kugler & Verhoogen (2012) with (a) scope for vertical product differentiation and (b) quality-innovation-to-sales ratio.
Table 2: Robustness check - quantification of model when including costs for electricity
Table 3: Robustness check - alternative marginal cost parameter
Table 4: Robustness check - quantification of model with sector-specific Pareto shape parameters
Table 5: Robustness checks - alternative variable trade costs
Table 6: Robustness check - differences in external finance across sectors
Table 7: Additional estimation results for Peru, 2016
Table 8: Additional estimation results for Mexico, 2010

REFERENCES

AGHION, P., T. FALLY, and S. SCARPETTA, "Credit Constraints as a Barrier to the Entry and Post-Entry Growth of Firms," *Economic Policy* 22 (2007), 732–79.

ALTOMONTE, C., D. FAVOINO, M. MORLACCO, and T. SONNO, "Markups, Intangible Capital and Heterogeneous Financial Frictions," CEP Discussion Paper No. 1740, Centre for Economic Performance, LSE, London, UK, 2021.

ANDERSON, J. E., and E. VAN WINCOOP, "Trade Costs," *Journal of Economic Literature* 42 (2004), 691–751.

ANTONIADES, A., "Heterogeneous Firms, Quality, and Trade," *Journal of International Economics* 95 (2015), 263–73.

ANTRÀS, P., and R. J. CABALLERO, "Trade and Capital Flows: A Financial Frictions Perspective," *Journal of Political Economy* 117 (2009), 701–44.

———, M. A. DESAI, and C. F. FOLEY, "Multinational Firms, FDI Flows, and Imperfect Capital Markets," *Quarterly Journal of Economics* 124 (2009), 1171–219.

ARCHIBUGI, D., A. FILIPPETTI, and M. FRENZ, "Economic Crisis and Innovation: Is Destruction Prevailing over Accumulation?" *Research Policy* 42 (2013), 303–14.

ARKOLAKIS, C., A. COSTINOT, and A. RODRIGUEZ-CLARE, "New Trade Models, Same Old Gains?" *American Economic Review* 102 (2012), 94–130.

AW, B. Y., and Y. LEE, "Demand, Costs and Product Scope in the Export Market," *European Economic Review* 100 (2017), 28–49.

AXTELL, R. L., "Zipf Distribution of U.S. Firm Sizes," *Science* 293 (2001), 1818–20.

BALDWIN, R., and J. HARRIGAN, "Zeros, Quality, and Space: Trade Theory and Trade Evidence," *American Economic Journal: Microeconomics* 3 (2011), 60–88.

BECK, T., "Bank Financing for SMEs—Lessons from the Literature," *National Institute Economic Review* 225 (2013), R23–38.

———, A. DEMIRGÜÇ-KUNT, and V. MAKSIMOVIC, "Financing Patterns around the World: Are Small Firms Different?" *Journal of Financial Economics* 89 (2008), 467–87.

BEHRENS, K., G. MION, Y. MURATA, and J. SÜDEKUM, "Trade, Wages, and Productivity," *International Economic Review* 55 (2014), 1305–48.

BERMAN, N., and J. HÉRICOURT, "Financial Factors and the Margins of Trade: Evidence from Cross-Country Firm-Level Data," *Journal of Development Economics* 93 (2010), 206–17.

BERNINI, M., S. GUILLOU, and F. BELLONE, "Financial Leverage and Export Quality: Evidence from France," *Journal of Banking & Finance* 59 (2015), 280–96.

BERTHOU, A., J. JONG-HYUN CHUNG, K. MANOVA, and C. SANDOZ DIT BRAGARD, "Trade, Productivity and (Mis)Allocation," CEP Discussion Papers No. 1668, Centre for Economic Performance, LSE, London, UK, 2020.

BLAUM, J., C. LELARGE, and M. PETERS, "The Gains from Input Trade with Heterogeneous Importers," *American Economic Journal: Macroeconomics* 10 (2018), 77–127.

BONFIGLIOLI, A., R. CRINÒ, and G. GANCIA, "Trade, Finance, and Endogenous Firm Heterogeneity," *Journal of the European Economic Association* 17 (2018), 79–130.

BROOKS, W., and A. DOVIS, "Credit Market Frictions and Trade Liberalizations," *Journal of Monetary Economics* 111 (2020), 32–47.

BUERA, F. J., J. P. KABOSKI, and Y. SHIN, "Finance and Development: A Tale of Two Sectors," *American Economic Review* 101 (2011), 1964–2002.

BUSTOS, P., "Trade Liberalization, Exports, and Technology Upgrading: Evidence on the Impact of MERCOSUR on Argentinian Firms," *American Economic Review* 101 (2011), 304–40.

CHANEY, T., "Liquidity Constrained Exporters," *Journal of Economic Dynamics and Control* 72 (2016), 141–54.

CIANI, A., and F. BARTOLI, "Export Quality Differentiation under Credit Constraints," *World Economy* 43 (2020), 1398–433.

CRINÒ, R., and L. OGLIARI, "Financial Imperfections, Product Quality, and International Trade," *Journal of International Economics* 104 (2017), 63–84.

CROUZET, N., "Aggregate Implications of Corporate Debt Choices," *Review of Economic Studies* 85 (2018), 1635–82.

CROZET, M., K. HEAD, and T. MAYER, "Quality Sorting and Trade: Firm-Level Evidence for French Wine," *Review of Economic Studies* 79 (2012), 609–44.

———, and P. KOENIG, "Structural Gravity Equations with Intensive and Extensive Margins," *Canadian Journal of Economics* 43 (2010), 41–62.

DE FIORE, F., and H. UHLIG, "Bank Finance versus Bond Finance," *Journal of Money, Credit and Banking* 43 (2011), 1399–421.

EATON, J., S. KORTUM, and F. KRAMARZ, "An Anatomy of International Trade: Evidence from French Firms," *Econometrica* 79 (2011), 1453–98.

ECKEL, C., L. IACOVONE, B. JAVORCIK, and J. P. NEARY, "Multi-Product Firms at Home and Away: Cost- versus Quality-Based Competence," *Journal of International Economics* 95 (2015), 216–32.

EGGER, P. H., and C. KEUSCHNIGG, "Innovation, Trade, and Finance," *American Economic Journal: Microeconomics* 7 (2015), 121–57.

———, and ———, "Access to Credit and Comparative Advantage," *Canadian Journal of Economics* 50 (2017), 481–505.

FAN, H., E. L.-C. LAI, and Y. A. LI, "Credit Constraints, Quality, and Export Prices: Theory and Evidence from China," *Journal of Comparative Economics* 43 (2015), 390–416.

———, Y. A. LI, S. XU, and S. R. YEAPLE, "Quality, Variable Markups, and Welfare: A Quantitative General Equilibrium Analysis of Export Prices," *Journal of International Economics* 125 (2020), 103327.

FEENSTRA, R. C., Z. LI, and M. YU, "Exports and Credit Constraints under Incomplete Information: Theory and Evidence from China," *Review of Economics and Statistics* 96 (2014), 729–44.

FLACH, L., and F. UNGER, "Quality and Gravity in International Trade," *Journal of International Economics* 137 (2022), 103578.

FOELLMI, R., S. LEGGE, and A. TIEMANN, "Innovation and Trade in the Presence of Credit Constraints," *Canadian Journal of Economics* 54 (2021), 1168–205.

FOLEY, C. F., and K. MANOVA, "International Trade, Multinational Activity, and Corporate Finance," *Annual Review of Economics* 7 (2015), 119–46.

FORLANI, E., R. MARTIN, G. MION, and M. MUÛLS, "Unraveling Firms: Demand, Productivity and Markups Heterogeneity," CEP Discussion Paper No. 1402, Centre for Economic Performance, LSE, London, UK, October 2022.

FOSTER, L., J. HALTIWANGER, and C. SYVERSON, "Reallocation, Firm Turnover, and Efficiency: Selection on Productivity or Profitability?" *American Economic Review* 98 (2008), 394–425.

GARCIA-MARIN, A., and N. VOIGTLÄNDER, "Exporting and Plant-Level Efficiency Gains: It's in the Measure," *Journal of Political Economy* 127 (2019), 1777–825.

HALLAK, J. C., and J. SIVADASAN, "Product and Process Productivity: Implications for Quality Choice and Conditional Exporter Premia," *Journal of International Economics* 91 (2013), 53–67.

HEAD, K., T. MAYER, and M. THOENIG, "Welfare and Trade without Pareto," *American Economic Review* 104 (2014), 310–16.

HOLMSTROM, B., and J. TIROLE, "Financial Intermediation, Loanable Funds, and the Real Sector," *Quarterly Journal of Economics* 112 (1997), 663–91.

HOTTMAN, C. J., S. J. REDDING, and D. E. WEINSTEIN, "Quantifying the Sources of Firm Heterogeneity," *Quarterly Journal of Economics* 131 (2016), 1291–364.

HSIEH, C.-T., and P. J. KLENOW, "Misallocation and Manufacturing TFP in China and India," *Quarterly Journal of Economics* 124 (2009), 1403–48.

IMPULLITTI, G., and O. LICANDRO, "Trade, Firm Selection and Innovation: The Competition Channel," *Economic Journal* 128 (2018), 189–229.

IRLACHER, M., and F. UNGER, "Capital Market Imperfections and Trade Liberalization in General Equilibrium," *Journal of Economic Behavior & Organization* 145 (2018), 402–23.

JOHNSON, R. C., "Trade and Prices with Heterogeneous Firms," *Journal of International Economics* 86 (2012), 43–56.

KHANDELWAL, A., "The Long and Short (of) Quality Ladders," *Review of Economic Studies* 77 (2010), 1450–76.

KOHN, D., F. LEIBOVICI, and M. SZKUP, "Financial Frictions and New Exporter Dynamics," *International Economic Review* 57 (2016), 453–86.

KUGLER, M., and E. VERHOOGEN, "Prices, Plant Size, and Product Quality," *Review of Economic Studies* 79 (2012), 307–39.

LEIBOVICI, F., "Financial Development and International Trade," *Journal of Political Economy* 129 (2021), 3405–46.

LILEEVA, A., and D. TREFLER, "Improved Access to Foreign Markets Raises Plant-Level Productivity… for Some Plants," *Quarterly Journal of Economics* 125 (2010), 1051–99.

MANOVA, K., "Credit Constraints, Heterogeneous Firms, and International Trade," *Review of Economic Studies* 80 (2013), 711–44.

———, and Z. ZHANG, "Export Prices across Firms and Destinations," *Quarterly Journal of Economics* 127 (2012), 379–436.

MELITZ, M. J., "The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity," *Econometrica* 71 (2003), 1695–725.

———, and S. J. REDDING, "New Trade Models, New Welfare Implications," *American Economic Review* 105 (2015), 1105–46.

MIDRIGAN, V., and D. Y. XU, "Finance and Misallocation: Evidence from Plant-Level Data," *American Economic Review* 104 (2014), 422–58.

MINETTI, R., and S. C. ZHU, "Credit Constraints and Firm Export: Microeconomic Evidence from Italy," *Journal of International Economics* 83 (2011), 109–25.

MUÛLS, M., "Exporters, Importers and Credit Constraints," *Journal of International Economics* 95 (2015), 333–43.

PAUNOV, C., "The Global Crisis and Firms' Investments in Innovation," *Research Policy* 41 (2012), 24–35.

ROBERTS, M. J., and D. SUPINA, "Output Price, Markups, and Producer Size," *European Economic Review* 40 (1996), 909–21.

———, D. Y. XU, X. FAN, and S. ZHANG, "The Role of Firm Factors in Demand, Cost, and Export Market Selection for Chinese Footwear Producers," *Review of Economic Studies* 85 (2017), 2429–61.

SECCHI, A., F. TAMAGNI, and C. TOMASI, "Export Price Adjustments under Financial Constraints," *Canadian Journal of Economics* 49 (2016), 1057–85.

SUTTON, J., *Technology and Market Structure: Theory and History*, Volume 1 of *MIT Press Books* (Cambridge, MA: MIT Press, 2001).

———, "Quality, Trade and the Moving Window: The Globalisation Process," *Economic Journal*, 117(524) (2007), F469–98.

———, "Competing in Capabilities: The Globalization Process", 2012, Oxford University Press, United Kingdom.

UNGER, F., "Credit Frictions, Selection into External Finance, and Gains from Trade," *Canadian Journal of Economics* 54 (2021), 1206–51.

VON EHRLICH, M., and T. SEIDEL, "Regional Implications of Financial Market Development: Industry Location and Income Inequality," *European Economic Review* 73 (2015), 85–102.

YEAPLE, S. R., "A Simple Model of Firm Heterogeneity, International Trade, and Wages," *Journal of International Economics* 65 (2005), 1–20.