Production Network Formation, Trade, and Welfare [*]

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Abstract

We study the aggregate implications of endogenous production network formation in a multi-location general equilibrium trade model. Firms form supplier and buyer linkages under matching frictions, generating a gravity structure of production networks. We analytically characterize the welfare gains from trade cost reductions relative to a benchmark model with fixed production networks. We calibrate the model to Chilean firm-to-firm data and show that it matches observed domestic and international network responses to tariff reductions. We find that endogenous networks substantially increase the welfare gains from trade, due to inefficiently low equilibrium networks and amplification effects through relationship-formation costs.

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1 Introduction

How do trade and productivity shocks impact aggregate economic activity and welfare? A growing body of research shows that production networks play a key role in transmitting and amplifying trade shocks (Caliendo and Parro, 2015; Carvalho, Nirei, Saito and Tahbaz-Salehi, 2021; Caliendo, Parro, Rossi-Hansberg and Sarte, 2018; Huo, Levchenko and Pandalai-Nayar, 2025). This work typically takes these networks as given. Yet these networks emerge from firms' endogenous decisions to form and maintain linkages with suppliers and buyers. How do such link formation decisions shape the aggregate effects of trade shocks?

Understanding the determinants and consequences of these endogenous connections requires recognizing that firms often face substantial frictions when forming production linkages across regions and countries. Beyond shipment costs associated with each transaction, firms face matching frictions in identifying and establishing trading relationships (Rauch, 1999; Allen, 2014; Bernard, Moxnes and Saito, 2019; Miyauchi, 2024; Startz, 2024). However, a gap remains in understanding how these firm-level decisions collectively shape the aggregate architecture of production networks, economic activities, and welfare across regions, both theoretically and quantitatively.

We address this gap by developing and analyzing a tractable, quantitative multi-location general equilibrium trade model that incorporates firms' production network formation. Our model embeds production network formation decisions by profit-maximizing firms in an otherwise standard trade model with input-output linkages, as reviewed by Costinot and Rodríguez-Clare (2014) and Antrás and Chor (2022). Firms form both supplier and buyer linkages across regions while facing shipment costs and matching frictions. Relationships materialize depending on the suppliers' and buyers' effort in relationship formation and the matching technology. We show that our model implies a gravity structure of production networks and bilateral trade. Production networks, in turn, shape aggregate economic activity across locations in general equilibrium. We use this framework to derive sufficient statistics for global and regional welfare and characterize the deviations from the fixed network environment.

An important feature of our framework is the inefficiencies in firms' production network formation decisions. Because of imperfect competition and matching externalities, firms' link formation decisions need not align with the social optimum. We identify two externalities associated with endogenous network formation decisions: the non-appropriability and the business-stealing effects of link formation. We solve for the planning problem and characterize a simple formula for taxes/subsidies on the cost of forming relationships with suppliers and buyers that balance these externalities. Our results extend the classical insights of Dixit and Stiglitz (1977) on entry into consumer markets, and of Hosios (1990) on two-sided matching markets, to multi-layered production networks spanning multiple locations.

To evaluate the impact of production network formation decisions and their inefficiencies on the aggregate economy, we derive a series of sufficient statistics for the welfare effects of changes in trade costs. The first set of *ex-ante* welfare sufficient statistics evaluates global welfare gains with respect to small trade cost changes. We show that these are proportional to the product of observed trade flows and trade cost changes, in line with results for fixed production networks in Atkeson and Burstein (2010) and Baqaee and Farhi (2024) (which in turn build on Hulten (1978)'s closed-economy insight). Due to equilibrium inefficiencies, the gains are multiplied by a scaling coefficient that generally differs from one. When networks are fixed, this coefficient exceeds one due to double marginalization in intermediate goods. When networks are endogenous, this scaling coefficient is further influenced by inefficiencies in equilibrium relationship-formation effort and by how these inefficiencies distort equilibrium trade flows.

The second set of results is *ex-post* sufficient statistics for welfare gains from trade with respect to (small or large) changes in intra-regional trade shares. Our derivations generalize familiar results for fixed production networks (e.g. Arkolakis, Costinot and Rodríguez-Clare 2012; Blaum, Lelarge and Peters 2018). In particular, our formula is multiplied by a scaling coefficient that differs from the fixed-network benchmark for two reasons, distinct from those driving the *ex-ante* sufficient statistics. First, endogenous network formation raises the responsiveness of trade flows to variable trade costs—the aggregate trade elasticity—by allowing supplier and buyer linkages to adjust. Second, trade cost shocks may directly affect the cost of relationship formation, further magnifying the gains from trade openness. This mechanism parallels trade models with firm entry or with capital accumulation, where entry or investment costs depend on traded intermediate inputs (Arkolakis et al., 2012; Costinot and Rodríguez-Clare, 2014; Ding, 2025).[1]

A key insight from our sufficient statistics analysis is that endogenous networks affect the aggregate trade and welfare through three margins: equilibrium inefficiencies, trade elasticities, and the amplification effects through relationship-formation costs. To show that this result holds in a variety of endogenous network frameworks, we follow the approach of Arkolakis et al. (2012) and derive macro restrictions that yield the same *ex-ante* and *ex-post* welfare sufficient statistics. We demonstrate that alternative matching market assumptions (e.g., matching occurs within each productivity segment, rather than randomly within location pairs) yield the same macro-restrictions, thereby providing robustness to our theoretical results. Moreover, we demonstrate that these restrictions hold across alternative microfoundations of network formation under suitable parametric assumptions, including relationship-specific fixed costs (Lim, 2018; Huneeus, 2018; Bernard, Dhyne, Magerman, Manova and Moxnes, 2022; Dhyne, Kikkawa, Kong, Mogstad and Tintelnot, 2023) or discrete supplier choices (Oberfield, 2018; Acemoglu and Azar,

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[1] Similar amplification forces appear in endogenous growth models, e.g., Rivera-Batiz and Romer (1991); Vom Lehn and Winberry (2022); Buera, Hopenhayn, Shin and Trachter (2023).

2020; Antràs and De Gortari, 2020; Eaton, Kortum and Kramarz, 2024). Taken together, these findings offer a unified framework that links endogenous production network formation to aggregate welfare outcomes.

In the final part of the paper, we quantify these channels using transaction-level administrative Chilean domestic and international firm-to-firm trade data. Before turning to model quantification, we present reduced-form evidence showing that trade shocks indeed induce a reorganization of supplier and buyer linkages, using Chile's recent trade agreements with the United States and China as natural experiments. Exploiting a difference-in-differences design with firms' pre-agreement import mix to construct an exposure measure, we find that firms more exposed to tariff reductions indeed expand international input sourcing along both the intensive margin (expenditure per foreign supplier) and the extensive margin (number of foreign suppliers). Notably, these firms also adjust their domestic networks, increasing both the number of domestic suppliers and buyers. Taken together, these results demonstrate that trade shocks systematically reshape firms' production networks with both foreign and domestic partners.

We calibrate our model to Chilean firm-to-firm trade data, matching both the cross-sectional patterns of firm-to-firm trade and the observed reorganization of production networks following import tariff reductions. We then conduct two experiments to gauge the welfare gains from trade by considering counterfactual scenarios of increasing trade costs and the associated welfare losses. First, we assess the impact of moderate international trade cost shocks on the Chilean economy. Raising iceberg trade costs from the U.S. and China to Chile by a magnitude comparable to the trade agreements discussed earlier (approximately a 6.5 percentage point increase in tariffs for all imports from these countries) reduces Chile's aggregate welfare by 0.88 percent. Under a fixed-network specification, by contrast, the welfare loss is 0.56 percent. Thus, allowing for endogenous networks increases the welfare losses by 60 percent. This difference arises because, in our baseline calibration, double marginalization and matching externalities generate distortions that suppresses link formation in the pre-shock equilibrium. As a result, when networks are endogenous, higher trade costs operate on an already depressed level of linkages and trade flows, magnifying the impact of the trade cost shock relative to the observed equilibrium trade flows.

Second, we quantify welfare gains from trade (GFT) relative to two counterfactual autarky scenarios: municipality autarky, in which all inter-municipality and international trade is shut down, and international autarky, which permits domestic trade across municipalities but eliminates international trade. Holding the trade elasticity constant, allowing for endogenous network formation increases the average GFT relative to municipality autarky from 191 to 401 percentage points—a 110 percent increase—reflecting the strong amplification of trade shocks when lower intermediate-input costs stimulate additional relationship formation. By contrast, GFT relative to international autarky increases more modestly, from 11.1 to 15.1 percentage points (a 36 percent increase). This difference occurs because firms can still reconfigure their domestic supplier relationships under international autarky, and this flexibility partially offsets the amplification force. More broadly, these comparisons suggest that the role of endogenous networks differs markedly depending on the nature of the trade shocks.

Taken together, our results show that endogenous formation of production networks is important in assessing the aggregate effects of trade shocks—both theoretically and quantitatively—through three key channels: equilibrium inefficiencies, trade elasticities, and multiplier effects arising from relationship-formation costs.

Related Literature We contribute to several strands of literature on international trade and macroeconomics. First, we contribute to the literature on production networks by developing a tractable quantitative multi-region general equilibrium trade model featuring endogenous production network formation and by characterizing its aggregate implications. Existing work has established that shocks propagate through fixed production networks. Existing work has also established that firms endogenously form production networks depending on the economic environment.[2] Some authors, such as Antràs and De Gortari (2020) and Eaton et al. (2024), incorporate discrete choices of suppliers in multi-location general equilibrium trade models with input-output linkages. However, this literature offers a limited theoretical characterization of how endogenous network formation under various frictions shapes the aggregate effects of trade shocks. We contribute by extending familiar *ex-ante* and *ex-post* welfare sufficient statistics in trade models with fixed production networks to the endogenous network environment.

Our emphasis on sufficient statistics relates to Baqaee, Burstein, Duprez and Farhi (2025), who provide a nonparametric accounting framework to evaluate the firm-level and aggregate effects of observed changes in production networks. A key distinction of our work is that we endogenize production network formation. We show that this feature crucially influences the aggregate effects of trade shocks, both theoretically and quantitatively.

Several existing papers study the equilibrium inefficiency of production network formation. Grossman, Helpman and Lhuillier (2023) and Grossman, Helpman and Sabal (2024) examine the equilibrium inefficiency from markup distortions in a stylized small open economy model. Boehm and Oberfield (2020) analyze a model with a discrete choice of suppliers under exogenous wedges and quantify the aggregate distortion. Acemoglu and Tahbaz-Salehi (2024) study a model where a discrete number of firms form linkages and bargain over surplus and highlight equilibrium inefficiency due to a hold-up problem. In contrast, our work emphasizes equilibrium inefficiencies arising from double marginalization and matching externalities. More broadly, we derive suffi-

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[2] See Johnson (2018), Bernard and Moxnes (2018), Antrás and Chor (2022), and Baqaee and Rubbo (2023) for recent reviews.

cient statistics for how these inefficiencies shape aggregate welfare in a multi-location general equilibrium environment with flexible geographic frictions, enabling direct mapping of our model to data for quantitative analysis.

We also contribute to the literature on search and matching frictions in trade and production network formation. Variable shipment costs alone have long been recognized as insufficient to explain observed trade frictions across regions and countries (Anderson and Van Wincoop, 2004). At the same time, a growing body of empirical evidence shows that firms face substantial search and matching frictions when forming supplier–buyer linkages.[3] Yet, we know little about how such frictions shape equilibrium cross-regional patterns or affect aggregate welfare. Our contribution is to provide an analytical characterization of how equilibrium inefficiencies, trade elasticities, and the amplification effects jointly shape aggregate welfare in such environments.

2 Model

The economy is segmented by a finite number of locations (such as regions or countries) denoted by $u, i, d \in \mathcal{N}$. In each location, there is a measure L_i of households. Each household supplies one unit of labor inelastically and earns a competitive wage w_i. There is a fixed mass of intermediate goods producers in each location, which we call "firms". We denote each of these firms in location i by $\omega \in \Omega_i$ and the measure of firms in location i by N_i. We denote the distribution function of total factor productivity (TFP) by firms in location i by $G_i(\cdot)$, which can flexibly depend on the location.

Firms produce differentiated intermediate goods, combining labor and intermediate goods. Intermediate goods can be traded across firms and locations connected by production linkages, subject to iceberg trade costs. These connections, in turn, are determined by firms' decisions to establish relationships under matching frictions. Local competitive retailers source intermediate goods from local firms and create retail goods within each location. The retail goods are used for final consumption and for firms' relationship-formation effort. We take the global nominal GDP as the numéraire unless explicitly stated otherwise.

We denote $S_{ui}(\omega) \subseteq \Omega_u$ to indicate the set of suppliers producing in u that a firm ω in location i can purchase from. Therefore, $\{S_{ui}(\cdot)\}_{u,i}$ summarize the structure of production networks in this economy. We first describe how production occurs given networks $\{S_{ui}(\cdot)\}_{u,i}$. We then

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[3] Allen (2014) and Demir, Javorcik and Panigrahi (2024b) show that internet connectivity facilitates the creation of supplier–buyer relationships. Startz (2024) documents that Nigerian importers incur large upfront costs to identify international suppliers. Miyauchi (2024) shows that firms rematch with alternative suppliers only gradually after unexpected bankruptcies, with rematching rates depending on the local density of suppliers. Cai, Lin and Szeidl (2024) finds that subsidized referrals significantly increased subsequent transactions in an experiment in the Chinese writing brush industry.

describe how these networks are endogenously formed by firms' decisions to form links under matching frictions.

2.1 Production given Networks

Firms. The production function of firm $\omega \in \Omega_i$ is given by

$$q_i(\omega) = z_i(\omega) \left(\frac{l_i(\omega)}{\beta}\right)^{\beta} \left(\frac{\tilde{q}_i(\omega)}{1-\beta}\right)^{1-\beta}, \tag{1}$$

where $z_i(\omega)$ is the TFP of firm ω, $l_i(\omega)$ is labor inputs, and $\tilde{q}_i(\omega)$ is the composite of intermediate inputs, β is the parameter proxying the input coefficient for labor. The composite of intermediate inputs is a constant elasticity of substitution (CES) aggregator of the input varieties sourced from their connected suppliers, given by

$$\tilde{q}_i(\omega) = \left(\sum_{u \in \mathcal{N}} \int_{\upsilon \in S_{ui}(\omega)} q_{ui}(\upsilon, \omega)^{\frac{\sigma-1}{\sigma}} d\upsilon\right)^{\frac{\sigma}{\sigma-1}}, \tag{2}$$

where $q_{ui}(\upsilon, \omega)$ is the quantity of input for the variety from connected supplier $\upsilon \in S_{ui}(\omega)$, and σ is the elasticity of substitution. From cost minimization, the marginal cost of production of firm ω is given by

$$c_i(\omega) = \frac{1}{z_i(\omega)} w_i^{\beta} \left(\sum_{u \in \mathcal{N}} \int_{\upsilon \in S_{ui}(\omega)} p_{ui}(\upsilon, \omega)^{1-\sigma} d\upsilon\right)^{\frac{1-\beta}{1-\sigma}}, \tag{3}$$

where $p_{ui}(\upsilon, \omega)$ is the intermediate goods price that supplier υ in location u charges to firm ω in location i. On top of these production costs, when a firm sells their intermediate goods to location d, they incur an iceberg trade cost of $\tau_{id} \geq 1$.

We assume that all firms are matched with a continuum of suppliers and, therefore, suppliers are under monopolistic competition to supply to each buyer. Thus, given the isoelastic intermediate goods demand, suppliers charge a constant markup to their marginal cost net of the iceberg trade cost;

$$p_{id}(\upsilon, \omega) = \tilde{\sigma} c_i(\upsilon) \tau_{id}, \tag{4}$$

where $\tilde{\sigma} = \sigma / (\sigma - 1)$ is the markup ratio.

Retailers. Perfectly competitive retailers in each location i combine intermediate inputs from all firms in location i and produce standardized nontradable retail goods. Their production function is given by

$$Q_i = g_i\left(\left\{q_i^R\left(\omega\right)\right\}_{\omega\in\Omega_i}\right), \tag{5}$$

where $g_i\left(\cdot\right)$ is a function that satisfies homogeneous of degree one, and $q_i^R\left(\omega\right)$ is the quantity of intermediate inputs from firm ω. The retail goods are used for final consumption and for firms' relationship-formation activity, as we describe further below.

We also assume that retailers have the entire bargaining power when purchasing intermediate inputs from each firm, and therefore, purchase goods at the marginal cost $c_i\left(\upsilon\right)$. From cost minimization, retail goods prices are given by

$$P_i = \tilde{g}_i\left(\left\{c_i\left(\omega\right)\right\}_{\omega\in\Omega_i}\right), \tag{6}$$

where $\tilde{g}_i\left(\cdot\right)$ is a solution to the cost minimization problem by retailers.

Final Consumers. Measure L_i households supply labor inelastically at wage w_i. They also own an equal share of local firms and earn their profits. Therefore, their budget constraint is given by

$$P_i Q_i^F = w_i + \frac{\Pi_i}{L_i}, \tag{7}$$

where Q_i^F is the amount of final consumption of retail goods per capita, and Π_i is aggregate profit by firms producing in location i.

2.2 Production Network Formation

Next, we describe how the production network structure, $\mathcal{S}_{ui}(\cdot)$, emerges endogenously from the network formation decisions of profit-maximizing firms subject to matching frictions.

2.2.1 Firms' Relationship-Formation Decisions

We assume that firms pay upfront costs to form supplier and buyer relationships. In particular, each firm ω located in i chooses the effort to form buyer relationships across destinations, $\{n_{id}^B\}_{d\in\mathcal{N}}$, and in forming supplier relationships across origins, $\{n_{ui}^S\}_{u\in\mathcal{N}}$.[4] These relationship-formation costs capture various costs involved in establishing successful trade links, such as identifying counterparts and designing or customizing products. Firms in the same location i with the same productivity z face the same equilibrium revenue and cost functions, and thus, they will make the same supplier and buyer decisions. Therefore, without loss of generality, we denote the

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[4] Whenever the equilibrium variables involve two locations with an upstream and downstream relationship (e.g., n_{id}^B, n_{ui}^S), we adopt the convention of denoting the subscripts in the order of upstream and then downstream locations.

optimal firm relationship-formation efforts by $\{n^B_{id}(\omega), n^S_{ui}(\omega)\}$ and $\{n^B_{id}(z), n^S_{ui}(z)\}$ interchangeably.

The probability that a relationship materializes successfully depends on the product of the effort to form buyer relationships across destinations and the respective matching probabilities, denoted by $\{m^B_{id}\}_{d\in\mathcal{N}}$ and $\{m^S_{ui}\}_{u\in\mathcal{N}}$. In equilibrium, these matching rates are endogenously determined by the aggregate bilateral efforts made by suppliers and buyers and the matching technology, as we describe in the next subsection. Since each firm is atomistic it takes these matching rates as given.

We assume that these relationship formation decisions entail isoelastic, upward-sloping costs. The total cost for the relationship formation effort is

$$f_i\left(\{n^B_{id}\}_d, \{n^S_{ui}\}_u\right) = e_i\left\{\sum_{d\in\mathcal{N}} f^B_{id}\frac{\left(n^B_{id}\right)^{\gamma^B}}{\gamma^B} + \sum_{u\in\mathcal{N}} f^S_{ui}\frac{\left(n^S_{ui}\right)^{\gamma^S}}{\gamma^S}\right\}, \tag{8}$$

where e_i is the unit cost of effort for relationship formation in location i (we describe how this is determined at the end of this section), and $\gamma^B > 1$ and $\gamma^S > 1$ are parameters capturing the decreasing returns in relationship-formation effort. $\{f^B_{id}\}$ and $\{f^S_{ui}\}$ are location-pair-specific relationship-formation cost shifters, capturing the possibility that the cost of identifying and forming successful supplier and buyer relationships may depend on geographic frictions. Here, we assume that these relationship-formation decisions are directed to a specific destination. In Section 5, we examine the robustness of our results to alternative specifications: one in which firms make uniform rather than destination-specific decisions, and another in which the relationship-formation decisions are directed toward a specific firm segment (e.g., distinguishing between high- and low-productivity suppliers), and establish broader isomorphisms.

Applying the law of large numbers, the cost function (3) can be written as a function of firm efficiency z and the measure of successful supplier matches, $n^S_{ui} \times m^S_{ui}$, such that

$$c_i\left(z, \{n^S_{ui}\}_u\right) = \frac{1}{z_i} w_i^\beta \left(\sum_{u\in\mathcal{N}} n^S_{ui} m^S_{ui} {C_{ui}}^{1-\sigma}\right)^{\frac{1-\beta}{1-\sigma}}, \tag{9}$$

where $C_{ui} \equiv \int_z \left(\tilde{\sigma} c_u(z)\tau_{ui}\right)^{1-\sigma} dG^B_{ui}(z)$ is the CES aggregator of the prices of suppliers producing in location u to supply to location i, and $G^B_{ui}(z)$ is probability density function of productivities weighted by the equilibrium effort for buyer link formation, i.e. $dG^B_{ui}(z) = n^B_{ui}(z)\, dG_u(z) / \int_{z'} n^B_{ui}(z')\, dG_u(z')$. Given this cost, a firm in location i with productivity z has expected revenue from each matched buyer from location d, $r_{id}(z, \{n^S_{ui}\}_u) = \left(\tilde{\sigma}\tau_{id} c_i\left(z, \{n^S_{ui}\}_u\right)\right)^{1-\sigma} D_d$, where D_d

is the average demand per buyer in location d net of the buyer-specific price index.[5]

The firm's total revenue from a destination d is the revenue per match times the expected measure of buyers, $n^B_{id} \times m^B_{id}$. The firm profit is then determined by the optimal relationship-formation decisions given by the difference between the variable profit and relationship-formation costs,

$$\tilde{\pi}_i\left(z\right) \equiv \max_{\{n^B_{id}\}_d, \{n^S_{ui}\}_u} \frac{1}{\sigma} \sum_{d \in \mathcal{N}} n^B_{id} m^B_{id} r_{id}(z, \{n^S_{ui}\}_u) - f_i\left(\{n^B_{id}\}_d, \{n^S_{ui}\}_u\right), \tag{10}$$

subject to (8) and (9). We impose a parameter restriction that $\delta \equiv (\sigma - 1) / \left(1 - \frac{1}{\gamma^B} - \frac{1-\beta}{\gamma^S}\right) > 0$, which guarantees that firms make positive sales and profit. The following lemma characterizes the solution to this problem.

Lemma 1. *Consider the optimization problem* (10) *and let* $\delta > 0$. *Then,*
a) The solution to the problem (10) is given by

$$n^B_{id}\left(z\right) = a^B_{id} z^{\frac{\delta}{\gamma^B}}, \qquad n^S_{ui}\left(z\right) = a^S_{ui} z^{\frac{\delta}{\gamma^S}}, \tag{11}$$

where $a^B_{id} \equiv \left(\Gamma^B_i \frac{X_{id}}{e_i f^B_{id}}\right)^{\frac{1}{\gamma^B}}$ *and* $a^S_{ui} \equiv \left(\Gamma^S_i \frac{X_{ui}}{e_i f^S_{ui}}\right)^{\frac{1}{\gamma^S}}$ *with* $\Gamma^S_i, \Gamma^B_i > 0$ *defined in Appendix A.1, and* X_{id} *is aggregate nominal sales of intermediate goods from* i *to* d.
b) Furthermore, the unit cost of a firm in location i *with productivity* z, $c_i\left(z\right)$, *can be expressed as*

$$c_i\left(z\right) = C_i z^{-\frac{\delta}{\gamma^S}\frac{1-\beta}{\sigma-1}-1}, \qquad C_i^{1-\sigma} \equiv w_i^{\beta(1-\sigma)} \left(\sum_{u \in \mathcal{N}} a^S_{ui} m^S_{ui} C^{1-\sigma}_{ui}\right)^{1-\beta}, \tag{12}$$

The proof of this lemma and all other propositions are in Appendix A. The Lemma extends the characterization in the single location environment in Demir, Fieler, Xu and Yang (2024a) to many locations. It implies that optimal relationship-formation decisions $\{n^B_{id}\left(z\right), n^S_{ui}\left(z\right)\}$ are multiplicatively separable between the firm-specific component that is iso-elastic in productivity z and the location-pair-specific components $\{a^B_{id}, a^S_{ui}\}$. Note that, the unit cost $c_i\left(z\right)$ declines faster than z^{-1}, since more productive firms invest more heavily in supplier links (equation 11), thereby achieving disproportionately lower production costs.

The firm's total revenue (excluding that to retailers) is

$$r^*_i\left(z\right) = \tilde{\sigma}^{1-\sigma} D^*_i C_i^{1-\sigma} z^{\delta}, \qquad D^*_i = \sum_{d \in \mathcal{N}} a^B_{id} m^B_{id} D_d \tau_{id}^{1-\sigma}. \tag{13}$$

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[5] Specifically, $D_d \equiv \int_{\omega \in \Omega_d} \mathcal{D}_d(\omega) / \left(\sum_{u \in \mathcal{N}} \int_{v \in S_{ui}(\omega)} p_{ui}\left(v, \omega\right)^{1-\sigma} dv\right) dG^S_d\left(\omega\right)$, where $dG^S_d\left(\omega\right)$ is probability density function of productivities weighted by the intensity of supplier link formation effort by firms in location d, and $\mathcal{D}_d\left(\omega\right)$ is the total intermediate input demand by firm ω in d.

In addition, we can substitute these results in equation (10) to obtain firm profit as a constant fraction of revenue,

$$\tilde{\pi}_i\left(z\right) = \frac{1}{\sigma}\left(1 - \left(\frac{1}{\gamma^B} + \frac{1-\beta}{\gamma^S}\right)\right) r_i^*\left(z\right), \tag{14}$$

where $\frac{1}{\gamma^B}$ and $\frac{1-\beta}{\gamma^S}$ correspond to the fraction of firms' variable profit that goes to buyer and supplier link formation efforts, respectively.

Finally, we describe how the unit cost of relationship-formation effort, e_i, is determined. In practice, forming production networks entails diverse types of activities, such as advertising and sales promotion, identifying potential partners, developing prototypes, and designing or customizing products, which require both labor and material inputs. We model these heterogeneous relationship-formation activities as a Cobb–Douglas aggregator of labor and retail goods. Under cost minimization, the unit cost of relationship formation effort is given by:

$$e_i = \left(w_i\right)^{\mu}\left(P_i\right)^{1-\mu}, \tag{15}$$

where μ is the labor coefficient in relationship-formation effort.

2.2.2 Matching Technology and Aggregation

We now describe how the equilibrium matching rates between suppliers and buyers, m_{ud}^S and m_{ud}^B, are determined. We follow the labor search-and-matching literature and represent the process through an aggregate matching technology that links the bilateral efforts of relationship formation by the suppliers and buyers to the measure of successful relationships (Diamond 1982; Mortensen 1986; Pissarides 1985). Specifically, we assume that the aggregate number of successful matches between locations, M_{ud}, is governed by a Cobb–Douglas matching function:

$$M_{ud} = \kappa_{ud}\left(\overline{M}_{ud}^B\right)^{\lambda^B}\left(\overline{M}_{ud}^S\right)^{\lambda^S}, \tag{16}$$

where λ^B, $\lambda^S \geq 0$ denote the elasticities of total matches created for the pair of regions with respect to the aggregate effort for buyer and supplier link formation, respectively;[6] κ_{ud} is the parameter governing the efficiency of matching technology that can flexibly depend on the location pairs; and $\overline{M}_{ud}^B = N_u \int_z n_{ud}^B(z)dG_u(z)$ and $\overline{M}_{ud}^S = N_d \int_z n_{ud}^S(z)dG_d(z)$ are aggregate efforts for buyer and supplier link formation.

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[6] Notice that λ^B represents the elasticity with respect to the aggregate efforts for *buyer* link formation (by the suppliers), and λ^S represents the elasticity with respect to aggregate efforts for *supplier* link formation (by the buyers).

Given M_{ud}, the matching rates m^B_{ud} and m^S_{ud} are determined as:

$$m^B_{ud} = \frac{M_{ud}}{\overline{M}^B_{ud}}, \qquad m^S_{ud} = \frac{M_{ud}}{\overline{M}^S_{ud}}. \tag{17}$$

The following lemma provides an analytical expression of the aggregate production networks and trade flows.

Lemma 2. *The measure of supplier-to-buyer relationships from supplier location u to buyer location d (extensive margin), M_{ud}, and the average transaction volume per relationship (intensive margin), $\overline{r}_{ud}$, are given by the following gravity equations:*

$$M_{ud} = \varrho^E \chi^E_{ud} \zeta^E_u \xi^E_d, \quad \overline{r}_{ud} = \varrho^I \chi^I_{ud} \zeta^I_u \xi^I_d, \tag{18}$$

with bilateral resistance shifters

$$\chi^E_{ud} = \left[\kappa_{ud} \left(f^B_{ud}\right)^{-\tilde{\lambda}^B} \left(f^S_{ud}\right)^{-\tilde{\lambda}^S} \left(\tau^{1-\sigma}_{ud}\right)^{\tilde{\lambda}^B+\tilde{\lambda}^S}\right]^{\frac{1}{1-\tilde{\lambda}^S-\tilde{\lambda}^B}}, \quad \chi^I_{ud} = \left(\tau_{ud}\right)^{1-\sigma},$$

where we define $\tilde{\lambda}^S \equiv \lambda^S/\gamma^S$, $\tilde{\lambda}^B \equiv \lambda^B/\gamma^B$; $\{\varrho^E, \varrho^I\}$ are constants invariant across locations, and the origin and destination shifters $\{\zeta^E_u, \xi^E_d, \zeta^I_u, \xi^I_d\}$ are given in Appendix A.2.

This lemma shows that aggregate trade flows follow a gravity structure, where the extensive and intensive margins have distinct geographic structures. The intensive margin is only affected by the iceberg trade cost, $(\tau_{ud})^{1-\sigma}$, as the matching frictions do not affect trade flows once a link is formed. The extensive margin is, in addition, affected by the matching technology, κ_{ud}, and the bilateral relationship-formation cost shifters, f^B_{ud} and f^S_{ud}.

For later analysis, we define trade elasticity as the partial derivative of aggregate bilateral trade flows, X_{ud}, with respect to iceberg cost, τ_{ud}, holding factor and intermediate goods prices as given:

$$\varepsilon \equiv \frac{\sigma - 1}{1 - \tilde{\lambda}^S - \tilde{\lambda}^B}. \tag{19}$$

Notice that the trade elasticity ε is weakly larger than the elasticity of substitution for intermediate inputs $\sigma - 1$ due to the reorganization of production linkages in response to trade costs.

2.3 General Equilibrium

The general equilibrium is defined by the set of prices $\{p_{id}(\upsilon, \omega), P_i, w_i, e_i\}$ and quantities $\{q_{id}(\omega, \psi)$, $q^R_i(\omega)$, Q_i, $n^B_{id}(\omega)$, $n^S_{ui}(\omega)$, $l_i(\omega)\}$ with which (i) households maximize consumption given the budget constraint (7) with income from firm profit given by $\Pi_i = N_i \int_z \tilde{\pi}_i(z)\, dG_i(z)$; (ii) firms make optimal pricing and production decisions for intermediate goods (3), (4) and relationship-formation decisions (10); (iii) retailers make optimal production decisions for retail goods (6); and (iv) intermediate goods, retail goods, and labor markets clear (see Appendix A.3 for precise market clearing conditions).

The following proposition shows that our model yields a tractable mathematical structure.

Proposition 1. *The equilibrium satisfies the following properties:*
a) Equilibrium wages $\{w_i\}$ and cost shifters $\{C_i\}$ solve the following set of equations

$$w_i^{1+\tilde{\lambda}^B \mu \frac{\varepsilon}{\sigma-1}} C_i^{\varepsilon\left(1+\tilde{\lambda}^B \frac{1-\mu}{\sigma-1}\right)} = \frac{1}{L_i} \sum_d K_i^U K_d^D \chi_{id}^I \chi_{id}^E w_d^{\left(\frac{1-\beta\sigma}{1-\beta}-\tilde{\lambda}^S \mu\right)\frac{\varepsilon}{\sigma-1}} C_d^{\varepsilon\left(\frac{1}{1-\beta}-\tilde{\lambda}^S \frac{1-\mu}{\sigma-1}\right)}, \tag{20}$$

$$w_i^{1-\left(\frac{1-\beta\sigma}{1-\beta}-\tilde{\lambda}^S \mu\right)\frac{\varepsilon}{\sigma-1}} C_i^{-\varepsilon\left(\frac{1}{1-\beta}-\tilde{\lambda}^S \frac{1-\mu}{\sigma-1}\right)} = \frac{1}{L_i} \sum_u K_u^U K_i^D \chi_{ui}^I \chi_{ui}^E w_u^{-\tilde{\lambda}^B \mu \frac{\varepsilon}{\sigma-1}} C_u^{-\varepsilon\left(1+\tilde{\lambda}^B \frac{1-\mu}{\sigma-1}\right)}, \tag{21}$$

where $\{K_i^U, K_i^D\}$ are exogenous constants defined in Appendix A.4.
b) If $\frac{\beta(\sigma-1)}{1-\beta} \geq (1-\mu)\left(\tilde{\lambda}^B + \tilde{\lambda}^S\right)$ and $\left(\frac{1-\beta\sigma}{1-\beta} - \tilde{\lambda}^S \mu\right)\frac{\varepsilon}{\sigma-1} \leq 1$, the equilibrium exists and is unique up-to-scale.

Part (a) of this proposition shows that the key region-level economic variables, $\{w_i, C_i\}$, can be solved using only two sets of fixed-point equations, which drastically simplifies the solution of the model with endogenous networks. The mathematical structure of the equilibrium system is similar to the ones that commonly appear in multi-location general equilibrium trade and spatial models. Therefore, we can apply existing techniques to establish positive properties of the equilibrium system, such as equilibrium uniqueness conditions as in Part (b) of this proposition, as an application of Allen, Arkolakis and Li (2024). Furthermore, we can apply the exact-hat algebra approach of Dekle, Eaton and Kortum (2008) to solve for counterfactual equilibrium changes given external shocks as long as we set the values of the structural parameters $\{\sigma, \beta, \mu, \tilde{\lambda}^B, \tilde{\lambda}^S\}$ and the observed aggregate trade flows, $\{X_{id}\}$. We use this approach for our quantitative analysis in Section 7, extended to a multi-sector environment.

A special case with $\lambda^S = \lambda^B = 0$ corresponds to a scenario where production networks are fixed. In our analysis below, we refer to this case as "fixed production networks" and contrast it to our baseline with endogenous production networks. To eliminate spending for relationship formation, we simultaneously take the limit $\gamma^S, \gamma^B \to \infty$ when we implement the "fixed production network" case.

3 Planning Problem and Equilibrium Inefficiency

An important feature of our model is the equilibrium inefficiency resulting from imperfect competition and matching externalities associated with network formation decisions. To analyze how these inefficiencies shape aggregate welfare, we solve a planning problem. We consider a global planner that controls all locations and has a set of policy tools that differ across origin-destination pairs but are uniform within each pair of locations.[7] First, the planner can introduce ad-valorem subsidies for intermediate goods sales specific to origin i and destination d, s^I_{id}. Under these subsidies, the intermediate goods prices change from equation (4) to

$$p_{id}(\upsilon,\omega) = \left(1 - s^I_{id}\right) \tilde{\sigma} c_i(\upsilon)\, \tau_{id}. \tag{22}$$

Second, the planner can introduce ad-valorem taxes for relationship formation for supplier and buyer links, t^S_{id} and t^B_{id}, for each pair of locations. Therefore, total costs for relationship formation by firms in location i is modified from equation (8) as

$$f_i\left(\{n^B_{id}\}_d, \{n^S_{ui}\}_u\right) = e_i \left\{ \sum_{d\in\mathcal{N}} \left(1 + t^B_{id}\right) f^B_{id} \frac{\left(n^B_{id}\right)^{\gamma^B}}{\gamma^B} + \sum_{u\in\mathcal{N}} \left(1 + t^S_{ui}\right) f^S_{ui} \frac{\left(n^S_{ui}\right)^{\gamma^S}}{\gamma^S} \right\}. \tag{23}$$

Finally, we introduce lump-sum transfers for households in location i, T^F_i, so that households' budget constraint is modified from equation (7) to $P_i Q^F_i = w_i + \frac{\Pi_i}{L_i} + T^F_i$.

The planner chooses the optimal policy to maximize the global welfare

$$\max_{\left\{\left\{s^I_{id}, t^B_{id}, t^S_{id}\right\}_d, T^F_i\right\}_i} \mathcal{W} \equiv \sum_i \psi_i L_i Q^F_i \tag{24}$$

subject to equilibrium constraints and the government budget constraint, which we formally spell out in Appendix A.6. $\psi_i \geq 0$ corresponds to the welfare weights attached to the households in each location. The following proposition provides a simple formula for the optimal policy.

Proposition 2. *[Optimal Taxes and Subsidies] For any weakly positive welfare weights* $\{\psi_i\}$*, the optimal set of taxes and subsidies* $\left\{s^I_{id}, t^B_{id}, t^S_{id}\right\}$ *must satisfy*

$$s^I_{id} = \frac{1}{\sigma}, \qquad t^B_{id} = \frac{1}{\lambda^B} - 1, \qquad t^S_{id} = \frac{1}{\lambda^S}\left(1-\beta\right)\frac{E_d}{R_d} - 1, \tag{25}$$

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[7] Specifically, we rule out firm-level relationship-formation taxes within a location pair. With those taxes, the planner can address additional externalities arising from firm heterogeneity in the matching market, where lower-productivity firms create congestion externalities for more productive firms (Acemoglu, 2001; Bilal, 2023; Brancaccio, Kalouptsidi, Papageorgiou and Rosaia, 2023). We do not focus on this inefficiency as its presence does not affect the aggregate welfare effects of trade cost shocks in Section 4.

for all i, d*, where* $R_d \equiv \sum_\ell X_{d\ell}$ *and* $E_d \equiv \sum_\ell X_{\ell d}$*.*

The proposition illustrates how each set of taxes/subsidies corrects for each source of market failure. First, the intermediate goods subsidy s^I_{id} is set at a constant rate across location pairs to exactly offset the markups. These subsidies address the double marginalization distortions from imperfect competition and input-output linkages.

Second, taxes for buyer link formation, t^B_{id}, target the matching externality by balancing two potential inefficiencies: the non-appropriability effect and the business-stealing effect. The non-appropriability effects arise because suppliers capture only a fraction of social surplus as revenue. Business-stealing effects occur because an additional connection results in a loss of profit for other suppliers. When $\lambda^B = 1$, there is no externality in the matching rates with buyers (equations 16 and 17), and the business-stealing effect only arises through input substitution by buyers given connections. Serendipitously, the two effects exactly cancel each other, much like what happens in entry models with CES demand (Dixit and Stiglitz, 1977; Mankiw and Whinston, 1986). With $\lambda^B < 1$, optimal taxes for buyer link formation are positive in order to offset the congestion externality.

The optimal taxes for supplier link formation, t^S_{id}, similarly balance the non-appropriability effect and the business-stealing effect. However, the expression is slightly different from t^B_{id}. This difference stems from the fact that, while firms' incentive to form *buyer* links increases proportionally with revenue, firms' incentive to form *supplier* links increases proportionally with intermediate input expenditure, and $(1-\beta)\,E_d/R_d$ captures this ratio.

Proposition 2 can be rewritten in the form of a necessary condition for equilibrium efficiency.

Corollary 1. *[Constrained Efficiency] Suppose the subsidy for intermediate goods sales is set at the optimal level,* $s^I_{id} = 1/\sigma$*. Then, there exists welfare weights* $\{\psi_i\}$ *that maximize the global welfare with* $t^B_{id} = t^S_{id} = 0$ *for all* i, d *if and only if*

$$\lambda^B = 1, \qquad \lambda^S = 1 - \beta. \tag{26}$$

Furthermore, the supporting welfare weights ψ_i *are proportional to equilibrium retail prices* P_i*.*

This condition relates to Hosios (1990), which establishes a necessary condition for the efficiency of two-sided search and matching models between firms and workers.[8] They show that, when this knife-edge condition is satisfied, the equilibrium is (constrained) efficient since the hold-up problem that arises due to Nash bargaining—because firms cannot exploit the entire surplus from the match—exactly cancels out the congestion externalities. The intuition behind

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[8] See Brancaccio et al. (2023) for a related analysis in a partial-equilibrium two-sided matching model in the context of the dry bulk shipping market.

Corollary 1 is similar, with the non-appropriability effects taking the place of the hold-up problem, and the congestion externality arising from matching frictions and input substitution from other connected suppliers.[9] In what follows, we analyze how a potential deviation from constrained efficiency influences the aggregate effects of trade cost shocks.

4 Welfare Effects of Trade Shocks

We now turn to analyze the impacts of trade cost changes on aggregate welfare. Unless explicitly stated, we focus on the laissez-faire equilibrium without taxes and transfers. For expositional purposes, we focus on a shock in iceberg trade costs $\{d\ln\tau_{ij}\}$, while it is straightforward to extend our analysis to other shocks on technology, such as those on relationship-formation costs or firm productivity.

4.1 Ex-Ante Sufficient Statistics on Global Welfare

We first analyze the first-order effect of shocks on global welfare. Let us define global welfare according to equation (24). To isolate our focus from the redistribution effects, we set welfare weights ψ_i equal to each region's retail goods price, P_i. The following proposition provides a sharp characterization of the shock's first-order effect.

Proposition 3. *[Ex-ante sufficient statistics] The first-order effect of a shock in iceberg trade costs $\{d\ln\tau_{ij}\}$ on global welfare with welfare weights $\psi_i = P_i$ is given by:*

$$d\ln\mathcal{W} = -\frac{\varsigma}{\frac{\beta}{1-\beta}-\frac{1-\mu}{\sigma-1}\left(\tilde{\lambda}^B+\tilde{\lambda}^S\right)}\sum_{u,d}X_{ud}d\ln\tau_{ud}, \tag{27}$$

where ς is the ratio of nominal world GDP to nominal world intermediate goods expenditure by firms, given by:

$$\varsigma = \frac{\beta}{1-\beta}+\frac{1}{\sigma}-\frac{1-\mu}{\sigma}\left(\frac{1}{\gamma^B}+\frac{1-\beta}{\gamma^S}\right). \tag{28}$$

This proposition shows that, up to first order, global welfare changes are proportional to the product of trade flows and trade cost changes, scaled by a specific coefficient. Importantly, the expression depends only on the baseline trade flows and a set of structural parameters. In particular, it does not require solving for a counterfactual equilibrium, thereby providing a convenient

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[9] Interestingly, constrained efficiency requires the increasing returns to scale (IRS) matching function instead of the constant returns to scale (CRS) in the Hosios' environment. This difference reflects the presence of additional business-stealing effects through input substitution across multiple connected suppliers. See Miyauchi (2024) and Eaton et al. (2024) for empirical evidence that matching function in firm-to-firm trade exhibits IRS.

and powerful *ex-ante* sufficient statistic. The observation that changes in global welfare are proportional to nominal trade flows relates to the analysis of Atkeson and Burstein (2010) and Baqaee and Farhi (2024) with fixed production networks, who in turn build on Hulten (1978) for a closed economy. However, because of the presence of the equilibrium inefficiency discussed in Section 3, the coefficient may not be equal to one.[10]

To build intuition for Proposition 3, consider the special case with fixed production networks ($\lambda^S = \lambda^B = 0; \gamma^S, \gamma^B \to \infty$), which simplifies to

$$d \ln \mathcal{W}^{\text{Fixed}} = -\frac{\varsigma^{\text{Fixed}}}{\frac{\beta}{1-\beta}} \sum_{u,d} X_{ud} d \ln \tau_{ud}, \qquad \varsigma^{\text{Fixed}} = \frac{\beta}{1-\beta} + \frac{1}{\sigma}. \tag{29}$$

In the denominator of the coefficient, $\beta/(1-\beta)$ is the standard input-output multiplier, which captures the propagation of production cost shocks toward downstream firms. The numerator ς^{Fixed} is the GDP-to-intermediate-input-expenditure ratio. The coefficient $\varsigma^{\text{Fixed}}/\frac{\beta}{1-\beta}$ is greater than one, which reflects the fact that the equilibrium intermediate goods expenditure is inefficiently small due to double marginalization.

With endogenous networks, by contrast, equation (27) can be written as (see Appendix A.7):

$$d \ln \mathcal{W} = -\frac{\varsigma}{\frac{\beta}{1-\beta}} \sum_{u,d} X_{ud} \left(d \ln \tau_{ud} - \frac{1}{\sigma - 1} d \ln M_{ud} \right). \tag{30}$$

The comparison between equations (29) and (30) highlights two key departures of the endogenous network environment from the fixed-network environment. First, $d \ln M_{ud} \neq 0$, and hence the reorganization of networks may contribute to aggregate welfare changes through love-of-variety effects. To further understand its role, note from equations (27) and (30) that

$$\sum_{u,d} X_{ud} \frac{1}{\sigma - 1} d \ln M_{ud} = -\frac{\frac{1-\mu}{\sigma-1}\left(\tilde{\lambda}^B + \tilde{\lambda}^S\right)}{\frac{\beta}{1-\beta} - \frac{1-\mu}{\sigma-1}\left(\tilde{\lambda}^B + \tilde{\lambda}^S\right)} \sum_{u,d} X_{ud} d \ln \tau_{ud}. \tag{31}$$

Therefore, the second term in equation (30) is proportional to the first term (after the summation), with the coefficient of proportionality equal to or greater than 1. The numerator, $\frac{1-\mu}{\sigma-1}(\tilde{\lambda}^B + \tilde{\lambda}^S) = \frac{1-\mu}{\sigma-1}(\lambda^B/\gamma^B + \lambda^S/\gamma^S)$, reflects multiplier effects operating through relationship-formation costs. A reduction in iceberg trade costs lowers these costs in proportion to the input coefficient of retail goods for relationship formation, $1 - \mu$. This, in turn, raises buyer and supplier

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[10] Due to the Cobb-Douglas production and matching technology, aggregate trade cost shocks do not induce any reallocation of labor between production and relationship formation. Therefore, there are no changes in "allocative efficiency" in our framework (as highlighted, for example, by Baqaee and Farhi, 2020), and the only deviation from Hulten's characterization arises due to the distortion in pre-shock trade flows.

relationship-formation efforts with elasticities $1/\gamma^B$ and $1/\gamma^S$, respectively. The resulting increases in equilibrium link formation, with elasticities λ^B and λ^S, expand production networks and lower production costs via the love-of-variety channel with elasticity $1/(\sigma-1)$. These multiplier effects are present whenever matching elasticities are positive ($\lambda^S, \lambda^B > 0$), relationship-formation cost exhibit decreasing returns to scale ($\gamma^S, \gamma^B < \infty$), and the intermediate goods coefficient in relationship formation cost is positive ($\mu < 1$).

Second, the GDP-to-intermediate-input-expenditure ratio is smaller in the model with endogenous networks, i.e., $\varsigma < \varsigma^{\text{Fixed}}$ (equations 28 and 29), because firms use intermediate (or retail) goods for relationship-network formation purposes. This gap is present whenever $\gamma^B, \gamma^S < \infty$ and $\mu < 1$.

Together, these two departures imply that the endogenous network environment predicts a larger first-order aggregate effect (conditional on the observed trade flows $\{X_{ud}\}$) if and only if

$$\frac{\varsigma^{\text{Fixed}}}{\varsigma} < \frac{\frac{\beta}{1-\beta}}{\frac{\beta}{1-\beta} - \frac{1-\mu}{\sigma-1}\left(\tilde{\lambda}^B + \tilde{\lambda}^S\right)}. \tag{32}$$

The left-hand side measures the ratio of equilibrium intermediate input use between the fixed and endogenous network environments. The right-hand side measures the corresponding ratio of the social marginal value of intermediate inputs. If the private returns exceed the social returns, initial equilibrium trade flows are distorted downward, and the aggregate effects of trade cost changes are larger, holding the initial equilibrium trade flows fixed.

To further illustrate the role of inefficiency in link formation, in Appendix A.7, we show a version of Proposition 3 if the optimal sales subsidy $s^I_{id} = 1/\sigma$ is implemented in the initial equilibrium. In that case, the endogenous and fixed networks have identical first-order aggregate effects if $\lambda^B = 1$ and $\lambda^S = 1-\beta$, i.e., which yield a constrained-efficient equilibrium under the optimal sales subsidy (Corollary 1). In the absence of sales subsidies, the cut-off values for λ^B and λ^S are generally smaller because ς^{Fixed} is already distorted upward, and markup distortions additionally apply to relationship-formation costs.

It is also worth noting that, even if firms' relationship-formation effort is inefficient, first-order effects of shocks may not be affected by endogenous network formation. This happens, in particular, if $\mu = 1$, i.e., if labor is the only resource used for relationship-formation effort. In this case, even though labor may be misallocated between production and relationship-formation effort, intermediate goods are not used for these efforts and thus face no additional distortion. Consequently, the influence of endogenous networks on aggregate welfare effects of trade shocks depends not only on how far relationship-formation effort departs from the social optimum, but also on the extent to which such effort generates extra demand for intermediate inputs, which is governed by μ.

4.2 Ex-Post Sufficient Statistics on Each Location's Welfare

We now turn to the welfare of each region. There is no convenient *ex-ante* sufficient statistics expression for each region's welfare, unlike the global welfare with price weights as in the previous section. However, the following proposition presents a simple *ex-post* sufficient statistic for each location's welfare for any changes in trade costs.

Proposition 4. *[Ex-post sufficient statistics] For any magnitude of trade cost shocks that satisfies $d\ln\tau_{ii}=0$ for location i, changes in location i's real GDP is given by:*

$$d\ln Q_i^F=-\frac{1}{\varepsilon}\frac{1}{\frac{\beta}{1-\beta}-\frac{1-\mu}{\sigma-1}\left(\tilde{\lambda}^S+\tilde{\lambda}^B\right)}d\ln\Lambda_{ii}, \tag{33}$$

where ε is the trade elasticity defined by equation (19), and $\Lambda_{ii}=X_{ii}/\sum_u X_{ui}$ is the aggregate share of intermediate inputs by firms in location i sourced from location i.

Therefore, for any magnitude of the shocks (notice that the coefficient in front of $d\ln\Lambda_{ii}$ is constant), welfare changes are solely summarized by the changes in intra-region expenditure share. This result resonates with the familiar *ex-post* welfare sufficient statistics for welfare gains from trade with fixed production networks (Arkolakis et al. 2012; Blaum et al. 2018).

Notice that under the fixed network specification, this expression comes down to

$$d\ln Q_i^{F,\text{Fixed}}=-\frac{1}{\sigma-1}\frac{1}{\frac{\beta}{1-\beta}}d\ln\Lambda_{ii}^{\text{Fixed}}, \tag{34}$$

where $\sigma-1$ corresponds to the trade elasticity with the fixed network environment, and $(1-\beta)/\beta$ is the input-output multiplier. Comparing equations (33) and (34) reveals two key differences between the endogenous and fixed network environment. First, an additional amplification term, $\frac{1-\mu}{\sigma-1}\left(\tilde{\lambda}^S+\tilde{\lambda}^B\right)$, appears in the endogenous network case. This term coincides with the one that appears in the denominator of Proposition 3, and it reflects the multiplier effect of trade shocks through relationship-formation costs. This mechanism parallels trade models with firm entry or with capital accumulation, where entry or investment costs use traded intermediate inputs (Arkolakis et al., 2012; Costinot and Rodríguez-Clare, 2014; Ding, 2025). Second, trade elasticity is higher with endogenous networks than fixed networks, i.e., $\varepsilon>\sigma-1$ (see equation 19). This is because the adjustment of supplier and buyer networks acts as an additional substitution margin. This force decreases the welfare changes conditional on the same change in intra-region expenditure share.[11]

Notice that the deviations between the endogenous and fixed network environments differ from the first-order welfare effects discussed in Section 4.1. First, whereas equilibrium inefficiency was the key driver in Section 4.1, it does not appear in Proposition 4. This is because, under Cobb–Douglas production and matching technologies, aggregate trade cost shocks do not induce any reallocation of labor between production and relationship formation. Second, trade elasticities now play a role when considering large shocks or region-specific welfare changes, as endogenous networks determine how quickly trade flows reallocate in response to those shocks.

Proposition 4 is also inherently related to the first-order effects as analyzed in Proposition 3. To see the connection, we can rewrite equation (33) as

$$d\ln Q_i^F = \frac{\varsigma}{\frac{\beta}{1-\beta} - \frac{1-\mu}{\sigma-1}\left(\tilde{\lambda}^S + \tilde{\lambda}^B\right)} \times \frac{1}{\varsigma}\left(-\frac{1}{\varepsilon}d\ln\Lambda_{ii}\right), \tag{35}$$

where the first term in the right-hand side is the same coefficient as in Proposition 3. Notice that $-\frac{1}{\varepsilon}d\ln\Lambda_{ii}$ is the changes in terms-of-trade ($d\ln P_i - \sum_u \Lambda_{ui} d\ln P_u$) and $1/\varsigma$ is the Domar weight of intermediate goods sector. The term, $\frac{1}{\varsigma}\left(-\frac{1}{\varepsilon}d\ln\Lambda_{ii}\right)$ is analogous to Hulten's expression from terms-of-trade shocks to location i. The constant in front of this term reflects the equilibrium inefficiency, and is identical to the coefficient in Proposition 3.

4.3 Extension to Multiple Sectors

So far, we have focused on the environment where the only source of firm heterogeneity is the TFP. However, in reality, firms may produce different types of intermediate goods using different production technologies and may face different degrees of matching frictions. To accommodate such heterogeneity, we extend our model to incorporate multiple sectors $k, m \in K$ connected through input-output linkages following the specification of Caliendo and Parro (2015), as detailed in Appendix C. In this extended environment, production technology takes a Cobb-Douglas form with labor and intermediate inputs with expenditure shares, $\{\beta_{m,L}, \{\beta_{km}\}_k\}$, and intermediate inputs aggregate with elasticity of substitution, σ_k. Final consumption is Cobb-Douglas with sectoral share, α_k. Iceberg costs depends on location-and-sector pairs, $\tau_{ij,km}$. Matching occurs for each location-and-sector pairs with cost elasticities, $\{\gamma_k^B, \gamma_k^S\}$, matching elasticities, λ_{km}, and the labor share in relationship-formation costs, μ_k. The trade elasticities are sector-pair specific: $\varepsilon_{kl} = (\sigma_k - 1)/\left(1 - \lambda_{kl}^B/\gamma_k^B - \lambda_{kl}^S/\gamma_l^S\right)$.

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[11] See Boehm, Levchenko, Pandalai-Nayar and Toma (2024) for a related *ex-post* sufficient statistics under steady states in a dynamic trade model, where differences between short- and long-run trade elasticities arise from firms' entry decisions, analogous to the distinction between the trade elasticity ε and the elasticity of substitution $\sigma - 1$ here.

We show in Appendix C that this version of the model predicts gravity equations of trade flows for each sector pair. Consequently, we can use the exact-hat algebra approach to undertake counterfactual simulations. We also extend the optimal policy formula in Section 3 and the *ex-post* sufficient statistics in Section 4.2, where the Leontief inverse of the input-output matrix, adjusted by the relationship-formation cost multiplier, becomes the key statistic. Due to the potential misallocation across sectors, there are no convenient *ex-ante* sufficient statistics as in Section 4.1, and obtaining the welfare effects from an arbitrary shock generally requires solving the full equilibrium system, even if the shock is infinitesimal.

5 Robustness and Broader Isomorphisms

A key insight from our sufficient statistics analysis is that endogenous networks affect aggregate trade and welfare through three margins: equilibrium inefficiencies, trade elasticities, and the amplification effects through relationship-formation costs. In this section, we show that this insight holds in a variety of endogenous network models by following the approach of Arkolakis et al. (2012) and derive reduced-form macro restrictions that yield the same *ex-ante* and *ex-post* welfare sufficient statistics. This exercise serves two purposes. First, it investigates the robustness of our theoretical results to alternative assumptions about the matching technology (e.g., matching occurs within each productivity segment, rather than randomly within location pairs). Second, it connects our framework to alternative approaches to production network formation, such as relationship-specific fixed costs or discrete supplier choices, thereby providing a unified account that links endogenous network formation to aggregate outcomes.

Suppose that the economy satisfies the same three macro restrictions considered by Arkolakis et al. (2012) (i.e., trade balance, constant profit and labor share to intermediate goods sales, and constant aggregate trade elasticity).[12] We introduce two additional macro restrictions pertaining to endogenous production network formation. First, in response to trade cost shocks $\{d\ln\tau_{ui}\}$, the changes in aggregate bilateral linkages follow

$$\begin{aligned} d\ln M_{ud} = {} & (\delta_{L,U}+\delta_{Q,U}+\delta_{L,D}+\delta_{Q,D})\, d\ln X_{ud} \\ & -\delta_{L,U} d\ln w_u-\delta_{Q,U} d\ln P_u-\delta_{L,D} d\ln w_d-\delta_{Q,D} d\ln P_d, \end{aligned} \tag{36}$$

where $\delta_{L,U}$, $\delta_{Q,U}$, $\delta_{L,D}$, $\delta_{Q,D}$ are constant parameters capturing the reliance of link formation in labor and retail goods in upstream and downstream locations. In our baseline model, iso-elastic relationship-formation costs (8) and Cobb-Douglas matching technology (16) jointly imply that

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[12] If there are no intermediate goods, as originally considered by Arkolakis et al. (2012), the second condition comes down to the constant profit to GDP ratio. See Appendix B for the formal statements.

$\delta_{L,U} = \mu\tilde{\lambda}^B$, $\delta_{Q,U} = (1-\mu)\,\tilde{\lambda}^B$, $\delta_{L,D} = \mu\tilde{\lambda}^S$, and $\delta_{Q,D} = (1-\mu)\,\tilde{\lambda}^S$.

Second, the changes in retail goods prices are given by

$$d\ln P_i = \beta d\ln w_i + (1-\beta)\sum_u \Lambda_{ui}\left(d\ln P_u + d\ln\tau_{ui} - \nu d\ln M_{ui}\right). \tag{37}$$

Equation (37) is a version of Shephard's lemma, relating the retail price index of location i to the average input costs weighted by the expenditure share. ν is a constant parameter capturing the elasticity of input bundle price with respect to supplier linkages. In our baseline model, $\nu = 1/(\sigma-1)$ captures the love-of-variety in intermediate inputs.

Under these conditions, Proposition 3 generalizes to

$$d\ln\mathcal{W} = \frac{\varsigma}{\frac{\beta}{1-\beta} - \nu\left(\delta_{Q,U}+\delta_{Q,D}\right)}\sum_{u,d} X_{ud}\,d\ln\tau_{ud}, \tag{38}$$

where ς is the GDP-to-intermediate-goods-expenditure ratio, restricted to be constant as a part of our macro restrictions. Furthermore, Proposition 4 generalizes to

$$d\ln Q_i^F = -\frac{1}{\varepsilon}\frac{1}{\frac{\beta}{1-\beta} - \nu\left(\delta_{Q,U}+\delta_{Q,D}\right)}d\ln\Lambda_{ii}. \tag{39}$$

The intuition behind equations (38) and (39) is similar to that of Propositions 3 and 4. $\nu\left(\delta_{Q,U}+\delta_{Q,D}\right)$ in the denominators captures the multiplier effects through retail goods costs used for production network formation. The deviation of equation (38) from Hulten (1978) arises because of the potential equilibrium inefficiency in the size of the intermediate goods sector, ς.

It is easy to verify that our model in Section 2 satisfies our macro restrictions. In Appendix B, we also argue that they hold in alternative assumptions about the matching technology. First, they hold in an alternative specification where either the efforts for the supplier or buyer link formation are undirected toward a specific location. In those cases, the only difference from our main specification is the trade elasticity ε, which is smaller since it only depends on the relationship-formation cost and matching elasticities of one side. Second, they hold in a specification where relationship-formation effort is directed toward a specific firm-segment within a location (e.g., high- vs. low-productivity suppliers) rather than uniform efforts within a location pair. In this case, the sufficient-statistics expressions remain identical to those in Section 4. The reason is that, despite rich cross-sectional heterogeneity across firms, location-pair–specific trade cost shocks do not trigger any reallocation of relationship-formation effort across firm segments within the location pairs.

We also outline two alternative microfoundations of network formation that generate the same macro restrictions. The first is a model with relationship-specific fixed costs paid by suppliers: heterogeneous monopolistically competitive suppliers incur a fixed cost to form each buyer relationship. Extending Bernard, Moxnes and Ulltveit-Moe (2018) to a multi-location general equilibrium setting with roundabout inputs, we show that this environment satisfies our macro restrictions when productivity follows a power law.[13] In this case, trade elasticity is $\varepsilon = \gamma_C \theta$, where θ is the shape parameter of firms' productivity distribution and $\gamma_C > 1$ is a composite parameter that translates the productivity distribution to the marginal cost distribution. The elasticity of input bundle price with respect to supplier linkages is given by $\nu = 1/(\sigma - 1) - 1/\left(\gamma_C \theta\right)$, reflecting both love-of-variety and supplier selection.[14]

The second alternative microfoundation is based on discrete supplier choice. This framework—used by Oberfield (2018) and Acemoglu and Azar (2020) without geography, and by Antràs and De Gortari (2020) and Eaton et al. (2024) with geography—assumes competitive firms producing homogeneous intermediates, with buyers selecting the lowest-cost supplier. We show that a version of these models satisfies our macro restrictions if productivity follows a power-law distribution. The aggregate trade elasticity equals the Pareto shape parameter ($\varepsilon = \theta$), as in Ricardian models (Eaton and Kortum, 2002). Because firms face no resource costs in forming links and simply choose cost-minimizing suppliers under perfect competition and constant returns, all link-cost parameters are zero ($\delta_{L,U} = \delta_{Q,U} = \delta_{L,D} = \delta_{Q,D} = 0$). Hence $\nu(\delta_{Q,U} + \delta_{Q,D}) = 0$, the coefficient in equation (38) is one (with $\varsigma = \beta/(1-\beta)$ under perfect competition), and equation (39) reduces to the standard Arkolakis et al. (2012) formula with an input–output multiplier.

These isomorphism results imply that once the welfare-relevant elasticities in equations (38) and (39) are known, aggregate welfare can be inferred without taking a stand on the model's microfoundations. A natural question, then, is whether these elasticities can be estimated directly. In principle, the answer is yes: given data on $\{M_{ud}, X_{ud}, w_u, P_u, \tau_{ud}\}$, one could estimate regression models based on (38) and (39) to obtain $\{\delta_{L,U}, \delta_{Q,U}, \delta_{L,D}, \delta_{Q,D}, \beta, \nu\}$. In practice, however, credible identification requires exogenous variation that shifts each of the right-hand-side variables independently. Specifying a microfoundation helps to address this challenge by allowing us to measure parameters from alternative sources (e.g., aggregate national accounts) and by imposing a structure that reduces the dimensionality of the parameters to be estimated. In Section 7, we adopt this strategy, calibrating our baseline microfounded model in Section 2 to quantify the aggregate welfare implications of trade cost shocks.

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[13] Lim (2018); Huneeus (2018); Bernard et al. (2022); Dhyne et al. (2023) consider this microfoundation without multi-location dimension.

[14] Models with fixed costs to sell in a market, as in Melitz (2003) with tradable intermediate inputs, also satisfy the same macro restrictions under a Pareto productivity distribution. The only distinction from models with relationship-specific fixed costs is that the trade elasticity equals θ rather than $\gamma_C \theta > \theta$, since there is no selection at the buyer level. By contrast, models with fixed costs to source from a market, as in Antras, Fort and Tintelnot (2017), do not satisfy the constant trade elasticity restriction, owing to the combinatorial structure of firm-level sourcing decisions.

6 Data and Reduced-Form Evidence

In this section, we describe our data from Chile, which we use to quantify our theoretical predictions. We also use this data to provide reduced-form evidence that production networks reorganize in response to tariff changes from Chile's recent trade agreements.

6.1 Data Sources

Our primary data source is a firm-to-firm transaction-level data set that covers the universe of domestic and international trade by Chilean firms. For domestic firm-to-firm transaction data, we draw on the electronic receipts reported to the fiscal authority for the purpose of value-added tax (VAT) collections. Since 2018, all corporate entities in Chile are mandated to submit electronic receipts of all the transactions that occur across firms to the Chilean Internal Revenue Service, SII (for its acronym in Spanish).[15] Each receipt includes information on the supplier's and buyer's unique tax-ID, transaction dates and values, and the municipalities of the establishments where the transaction occurs. For our model calibration in Section 7, we use data from 2019. For our reduced-form analysis of bilateral trade agreements in Section 6.2, we use data from 2003 to 2007, which also come from the VAT records, but aggregated at the level of supplier's and buyer's unique tax-ID at the biannual frequency.[16]

For international firm-to-firm transaction data, we draw on customs data (Customs Agency, 2025). This data set reports the export and import activity of each tax-ID, with the information about the products traded, country of origin or destination, and transaction value. Importantly, the data also reports the identity of the foreign firm involved in the transaction, which allows us to construct the firm-to-firm international transaction information.

We merge these two data sets using the unique tax-ID that is common across sources. We also merge these data sets with balance sheet information (SII tax form 29) and labor information (SII tax form 1887) (Internal Revenue Service, 2025). We exclude tax IDs that report no value-added or employment, as well as samples that report negative values of value-added, sales, or

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[15] Informal firms in Chile, which do not appear in our data sets, represent only 2% of Chile's GDP.

[16] For the data in 2003 to 2007, only firms that have total expenditures on intermediates in a given year above US$390000 have to report this information, which account for around 80 percent of value added in the Chilean economy. See Huneeus (2018) for further details.

material inputs.[17] We also use the Inter-Country Input-Output (ICIO) sectoral tables from the Organization for Economic Cooperation and Development (OECD) to capture the international trade surrounding Chile for our model calibration (Norihiko, Alsamawi, Webb, Cimper, Zürcher and Pechansky, 2023).

6.2 Reduced-Form Evidence for Endogenous Production Networks

Before proceeding with the model quantification, we provide causal evidence that production networks endogenously reorganize in response to trade shocks. We also use it to calibrate our model for the quantitative analysis.

Specifically, we study the impacts of Chile's bilateral trade agreements with the United States (US) and China. Chile signed a Preferential Trade Agreement (PTA) with the U.S. in 2004 and a Free Trade Agreement (FTA) with China in 2006. Both of these agreements reduced the average tariffs from 6.9 percentage points to nearly zero percentage points, depending on the products traded (see Appendix D.2 for details). Previous studies have analyzed how these episodes affected Chile's aggregate product-level international imports (Fontagné, Guimbard and Orefice, 2022). Here, we instead focus on how these trade shocks have affected the architecture of international and domestic production networks.

A key challenge in identifying the impacts of these trade policy changes is to isolate them from general macroeconomic trends. A simple comparison of Chile's overall production network architecture before and after these trade agreements does not allow us to identify the impacts of trade policy shocks. Therefore, we employ a difference-in-differences design that exploits firm-level exposure to import tariff changes, constructed from each firm's pre-agreement mix of imported products and source countries (e.g., Goldberg, Khandelwal, Pavcnik and Topalova, 2010). Specifically, we estimate the following firm-level regression specification:

$$\Delta \ln y_\omega = \alpha \text{ImportTariffShock}_\omega + \zeta_{h(\omega)} + \beta' X_\omega + \epsilon_\omega, \tag{40}$$

where ω is the firm, Δ indicates that we take differences of variables between 2003 (pre-agreements) and 2007 (post-agreements), y_ω is the outcome variable of firm ω (e.g., number of import and do-

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[17] To secure privacy, the Central Bank of Chile (CBC) mandates that the development, extraction, and publication of the results should not allow the identification, directly or indirectly, of natural or legal persons. Officials of the CBC processed the disaggregated data and merged them across sources. The authors implemented all the analysis and neither involved nor compromised the CBC nor the Chilean tax authority. This study was developed within the scope of the research agenda conducted by the CBC in economic and financial affairs of its competence. The CBC has access to anonymized information from various public and private entities through collaboration agreements signed with these institutions. The information contained in the databases of the Chilean tax authority is of a tax nature originating in self-declarations of taxpayers presented to the authority; therefore, the veracity of the data is not its responsibility.

mestic production linkages), $\text{ImportTariffShock}_\omega$ is the proxy for firm-level import tariff shocks as we further discuss below, $\zeta_{h(\omega)}$ is the 6-digit sector fixed effect for firm ω's sector $h(\omega)$, X_ω is a vector of firm-level control variables, including the shares of imports in firms' total material inputs and a proxy for the firm-level export tariff shocks (import tariffs charged by the counterparty countries).[18]

Columns (1) and (2) of Table 1 present the estimation results of equation (40), using import linkages as an outcome variable. Here, we define the import shock as the weighted average of import tariff changes in the basket of imported goods, where the weights are based on the import shares in the pre-agreement period. Specifically,

$$\text{ImportTariffShock}_\omega \equiv \sum_n \sum_g \frac{\text{Import}_{\omega ng,t_0}}{\text{ImportSum}_{\omega,t_0}} \times \Delta \ln(1 + \mathcal{T}_{ng}), \tag{41}$$

where n is the origin country, g is the HS-6 product, $\text{Import}_{\omega ng,t_0}$ is the value of imports by firm ω from country n and product g in the baseline year $t_0 = 2003$, $\text{ImportSum}_{\omega,t_0} \equiv \sum_n \sum_g \text{Import}_{\omega ng,t_0}$ is firm ω's total import values in the baseline year, $\mathcal{T}_{ng}$ is the rate of applied import tariff for product g from country n. Intuitively, this variable measures the log-point change in international input costs that firm ω would experience, if there were no behavioral adjustments in sourcing decisions. The estimated coefficient on log total imports is -3.20 (Column 1), indicating a highly elastic import response to tariff reductions. The coefficient on the log number of foreign suppliers is -1.86 (Column 2), implying that over half of the overall import response arises from the extensive margin. Hence, the reorganization of international supplier linkages accounts for a substantial share of the total import adjustment, in line with our theoretical predictions.

Columns (3) and (4), in turn, present the impacts of import tariff shocks on domestic production linkages. Here, we define the import shock as the weighted average of import tariff changes in the basket of all sourced goods (from domestic and international suppliers), such that

$$\text{ImportTariffShock}_\omega \equiv \sum_n \sum_g \frac{\text{Import}_{\omega ng,t_0}}{\text{ImportSum}_{\omega,t_0} + \text{DomPurchase}_{\omega,t_0}} \times \Delta \ln(1 + \mathcal{T}_{ng}), \tag{42}$$

where the difference from equation (41) arises from the inclusion of total domestic material purchases by firm ω in the baseline period, $\text{DomPurchase}_{\omega,t_0}$, in the denominator of the weight. Intuitively, this term captures the log-point changes in *overall* intermediate input costs that firms

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[18] We control for pre-period import share in firms' total material purchases to deal with the concern that firms with a higher import penetration may have differential trends in outcome variables (Borusyak, Hull and Jaravel, 2022). We focus on import tariff changes, instead of export tariff changes, because of the significantly smaller number of firms that engage in exports than imports in Chile.

face, if there were no behavioral adjustments in sourcing decisions.[19] We find the coefficient of -1.23 for the number of domestic buyers and -1.48 for the number of domestic suppliers, indicating highly elastic adjustments in firms' domestic network linkages. Hence, the reduction in import tariffs not only expanded international sourcing relationships but also increased domestic buyer and supplier connections within Chile.

The positive effects on the number of domestic suppliers from import tariff reduction are notable, as it implies that the import tariff reduction complemented the formation of domestic supplier linkages, instead of substituting them. In recent literature, researchers have studied how the temporary international trade shocks affect domestic sales (Dhyne, Kikkawa, Mogstad and Tintelnot 2021; Dhyne, Kikkawa, Komatsu, Mogstad and Tintelnot 2024) and the formation of production linkages (Demir et al. 2024a; Huneeus 2018), following the design of Autor, Dorn and Hanson (2013). Interestingly, this line of research has not found significant impacts on the number of domestic supplier linkages from international demand shocks (Demir et al., 2024a) and from supply shocks (Huneeus, 2018). These differences potentially stem from the permanent feature of the import tariff reduction that we study. We show below that our model can rationalize these domestic production network responses through endogenous relationship-formation decisions.

Table 1: Impact of Import Tariff Shocks on International and Domestic Production Links

	Total Imports (1)	Number Int. Suppliers (2)	Number Dom. Buyers (3)	Number Dom. Suppliers (4)
Import Tariff Shock	-3.20	-1.86	-1.23	-1.48
	(1.26)	(0.71)	(0.97)	(0.39)
Number Observations		33260		
Sector FE (6 digit)		Yes		
Prior Import Share		Yes		
Export Shock Residualized		Yes		
Period		2003-2007		

Notes: This table reports the estimates of regression equation (40). Import shocks are defined by equation (41) for Columns (1)-(2) and by equation (42) for Columns (3)-(4). All outcome variables are log changes between 2003 (pre-agreements) and 2007 (post-agreements). The samples include all Chilean firms that exist in both 2003 and 2007. Export shocks are constructed similarly to import shocks and controlled for. Standard errors are computed following Borusyak et al. (2022). Appendix D.2 discusses further details about the trade agreements and present summary statistics about the overall tariff changes. Appendix D.3 presents a set of standard tests to assess the validity of the shift-share design, including placebo regressions as suggested by Borusyak et al. (2022).

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[19] We adopt this definition of the import shock when analyzing domestic network outcomes, instead of the one used in equation (41), to facilitate interpretation as the elasticity of domestic linkages with respect to firms' overall intermediate input costs. Since we always control for firms' import shares in total material inputs in the regressions, the identifying variation is the same between the two specifications.

7 Quantitative Analysis

In the final section, we calibrate our model using Chilean data to assess the quantitative implications of endogenous production network formation for the effects of trade cost shocks on aggregate welfare.

7.1 Calibration

We calibrate our multi-sector model in Section 4.3 to the Chilean economy for 2019. We define locations in our model as 345 within Chile and three international locations: the United States, China, and the Rest of the World. To avoid the sparseness of the sector-region trade flows, we broadly divide sectors into "goods" and "services" sectors, where "goods" sector includes agriculture and fishing, mining and quarrying, and manufacturing, and "services" sector includes all other sectors.

To undertake counterfactuals, we need to calibrate the baseline trade flows across locations and sectors $\{X_{ud,hk}\}$ and a subset of structural parameters $\{\alpha_k, \beta_{k,L}, \beta_{hk}, \mu_k, \gamma_k^B, \gamma_k^S, \sigma_k, \varepsilon_{hk}, \lambda_{hk}^B, \lambda_{hk}^S\}$.[20] We construct baseline trade flows $\{X_{ud,hk}\}$ using various data sources described in Section 6. For trade between municipalities within Chile, we aggregate our domestic firm-to-firm trade data, and for trade between Chilean municipalities and international countries, we aggregate our customs data. For trade across international countries that do not involve Chile, we obtain the values using the Inter-Country Input-Output (ICIO) table. The trade flows constructed in this way may not satisfy our model's equilibrium conditions. To enable well-defined counterfactuals, we adjust the trade flows so that they are consistent with the equilibrium conditions by interpreting that the observed trade flows involve measurement errors (see Appendix E.1 for details).

We now turn to the calibration of structural parameters, summarized in Table 2. We calibrate the final expenditure shares, $\{\alpha_k\}$, by aggregating our domestic firm-to-firm trade data and firm-level labor compensation to the sectoral level across all firms and municipalities.

We also calibrate the labor coefficients in production, $\{\beta_{k,L}\}$, and intermediate input coefficient in production, $\{\beta_{hk}\}$, using the same data sources. In our model, firms allocate labor and intermediate inputs to two distinct purposes: production and relationship formation. To correctly identify $\{\beta_{k,L}, \beta_{hk}\}$, we therefore compute expenditure shares after netting out the portion of inputs devoted to relationship formation activities—such as advertising, sales promotion, relationship maintenance, and product design or customization.

We measure the labor and intermediate input shares related to relationship formation as follows. For labor, we use the share of workers engaging in "Sales Promotion and Advertisement

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[20] See Appendix C.4.2 for the system of equations for the exact-hat algebra counterfactuals with multiple sectors.

Table 2: Calibrated Parameters

Parameters	Goods	Services	Description
α_k	0.25	0.75	Final consumption share
$\beta_{k,L}$	0.10	0.20	Labor coefficient in production
β_{lk}			Intermediate input coefficient in production
l: Goods Sector	0.49	0.12	
l: Services Sector	0.41	0.68	
μ_k	0.35	0.35	Labor coefficient in relationship-formation costs
γ_k^S	2.6	2.9	Search cost curvature w.r.t. suppliers
γ_k^B	2.8	2.4	Search cost curvature w.r.t. buyers
σ_k	4.1	3.8	Elasticity of substitution
ε_{lk}			Trade elasticity
l: Goods Sector	5.3	5.1	
l: Services Sector	5.0	4.8	
$\lambda_{kl}^S = \lambda_{kl}^B$ $(\forall k, l)$	0.56	0.56	Matching function elasticity

Services" (*Trabajadores de los servicios y vendedores de comercios y mercados*) according to Chile's official employment survey, *Encuesta Nacional de Empleo (ENE)*.[21] The share of labor in this classification accounts for 21 percent of total employment in 2019. For intermediate inputs, we use purchases from suppliers whose primary sector falls under the broad category of "Business and Production Services," excluding "Research and Development Services" and "Legal and Accounting Services" (CPC two-digit codes 83–89). This represents 11 percent of total firm costs (labor plus materials). We then compute sectoral values of $\{\beta_{k,L}, \beta_{hk}\}$ using aggregate labor compensation and intermediate input shares, after netting out the relationship-formation expenditures.

We also calibrate the labor share of relationship-formation costs, $\{\mu_k\}$, using the same data sources. As described above, relationship formation involves two types of expenditures: directly hired labor—measured by employment in "Sales Promotion and Advertisement Services"—and outsourced services—captured by intermediate input purchases from suppliers that engage in "Business and Production Services." Since these service providers themselves employ labor, with compensation accounting for 13% of their total costs, we compute μ_k as the weighted average of these two components.[22] Due to the lack of sector-specific occupation data, we assume a common

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[21] We use the ENE because the administrative employer–employee data lack occupation information. The ENE, conducted by the Chilean statistical agency *Instituto Nacional de Estadísticas (INE)*, classifies occupations using the *Clasificador Chileno de Ocupaciones (CIOU.cl)*, based on the ILO's international classification CIOU 08.

[22] Specifically, we calibrate μ_k as $\mu_k = 1 \times \mathcal{S} + 0.13 \times (1 - \mathcal{S})$, where $\mathcal{S}$ is the aggregate labor compensation times the aggregate employment share of workers with occupation "sales promotion and advertisement services" relative to the total of this compensation and intermediate input purchases from "Business and Production Services," excluding "Research and Development Services" and "Legal and Accounting Services." 0.13 is the aggregate labor share in total costs within those firms.

value of $\mu_k = \mu$ across sectors and obtain $\mu = 0.35$.[23]

To calibrate the relationship-formation cost elasticities, $\{\gamma_k^B, \gamma_k^S\}$, we use the model-predicted log-linear relationship between the number of suppliers and buyers and aggregate sales at the firm-level, given by

$$\ln \sum_{d \in \tilde{\mathcal{N}}} \sum_{l \in K} n_{id,kl}^{\mathcal{X}}(z) = \frac{1}{\gamma_k^{\mathcal{X}}} \ln r_{i,k}(z) + \phi_{i,k}^{\mathcal{X}}, \qquad \mathcal{X} \in \{S, B\} \tag{43}$$

for any subset of locations $\tilde{\mathcal{N}} \subset \mathcal{N}$, where $\{\phi_{i,k}^B, \phi_{i,k}^S\}$ is a composite variable that depend on location and sector but not by firm productivity z.[24] Specifically, we estimate $\{1/\gamma_k^B, 1/\gamma_k^S\}$ from the regression of the log number of domestic suppliers and buyers within Chile (by taking $\tilde{\mathcal{N}}$ as all municipalities within Chile) on the log of the aggregate intermediate goods sales, conditional on the location and sector fixed effects (capturing $\{\phi_{i,k}^B, \phi_{i,k}^S\}$). We find the values of $\{\gamma_k^B, \gamma_k^S\}$ ranging from 2.4 to 2.9, which satisfy our equilibrium assumptions $\gamma_k^B > 1$ and $\gamma_k^S > 1$.

We calibrate the elasticity of substitution σ_k using trade elasticities estimated in the existing literature. In our multi-sector environment, the implied trade elasticities are specific to origin and destination sectors: $\varepsilon_{kl} = (\sigma_k - 1)/\left(1 - \lambda_{kl}^B/\gamma_k^B - \lambda_{kl}^S/\gamma_l^S\right)$ (Section 4.3). For the goods sector, we choose σ_k so that the trade elasticity—averaged across the two destination sectors—matches 5.2, following Fontagné et al. (2022), who estimate this parameter using Chile's aggregate import responses to tariff changes. For the services sector, we set it to 4.9 based on Gervais and Jensen (2019), who estimate trade elasticities from U.S. domestic service trade flows. Given our calibrated values of $\{\gamma_{kl}^B, \gamma_{kl}^S\}$, these choices are feasible once we also select $\{\lambda_{kl}^B, \lambda_{kl}^S\}$, as described below.

We calibrate the matching function elasticities, $\{\lambda_{kl}^B, \lambda_{kl}^S\}$ to rationalize the impacts of trade liberalization on domestic supplier linkage, as documented in Table 1. The procedure is summarized below (see Appendix E.2 for details). First, for each sector k and origin country u, we construct the average import tariff changes $\tilde{\mathcal{T}}_{uk}$ as the value-weighted average across HS-6 products. Next, for each candidate value of $\{\lambda_{kl}^B, \lambda_{kl}^S\}$, we undertake the counterfactual simulations of the changes in the iceberg trade costs $\hat{\tau}_{ud,kl} = \Delta \ln(1 + \tilde{\mathcal{T}}_{uk})$. Notice that, even though $\hat{\tau}_{ud,kl}$ are common for all d, l, they have different effects across municipalities and sectors depending on the baseline import exposure to the U.S. and China. We then run the analogous regressions as in Table 1 using the model-predicted counterfactual changes as the location and sector within Chile as a sample. We look for the values of $\{\lambda_{kl}^B, \lambda_{kl}^S\}$ that minimize the squared distance between the regression coefficients on domestic suppliers in the data (Column 4) and in the model

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[23] Although certain activities classified as "Business and Production Services" may not correspond to location–*pair*–specific efforts (e.g., broad marketing campaigns), as discussed in Section 5, these distinctions are inconsequential conditional on the values of trade elasticities, which we separately calibrate below.

[24] This relationship is obtained by reformulating Lemma C.1 and equation (C.15) in Appendix C of our multi-sector model, which corresponds to Lemma 1 and equation (13) for the single sector case.

Table 3: Impact of Import Tariff Shocks: Model vs Data

	Untargeted			Targeted
	Total Imports (1)	Number Int. Suppliers (2)	Number Dom. Buyers (3)	Number Dom. Suppliers (4)
Data	-3.20	-1.86	-1.23	-1.48
	(1.26)	(0.71)	(0.97)	(0.39)
Model	-4.15	-1.66	-1.87	-1.48

Notes: "Data" reports the firm-level impacts of import tariff changes from equation (40), replicating Table 1. "Model" reports the corresponding regression using model-predicted counterfactual changes using our calibrated parameters targeting the last column, as discussed in Section 7.1 and Appendix E.2.

prediction. We use the regression coefficients on international production linkages and domestic buyers (Columns 1-3) as untargeted moments to assess the model fit.

Due to the limited variations in tariff changes outside tradable sectors, we assume that these parameters are common across all sectors $k, l \in K$. We also assume that the matching function elasticities are symmetric $\lambda^B = \lambda^S$ as these two parameters tend to jointly affect the equilibrium system and it is difficult to identify each of them separately.[25] Following this procedure, we obtain the estimate of $\lambda^S = \lambda^B = 0.56$.[26] Table 3 shows that the model-predicted regression coefficients under these parameter values align with the targeted reduced-form regression coefficients (Columns 4). Furthermore, our model predicts similar regression coefficients for other untargeted regression coefficients, and they lie within the confidence intervals of the estimates using actual data (Columns 1-3).

7.2 Impacts of Trade Cost Shocks

We begin by conducting counterfactual exercises with moderate import trade cost shocks. Specifically, we raise the iceberg trade costs from the U.S. and China to all Chilean municipalities by the same magnitude as the tariff reductions under the trade agreements analyzed in Section 6.2. We then examine how the resulting effects vary with the sign and magnitude of the shock.

Table 4 reports the results. To highlight the role of the endogenous networks, we undertake this simulation under two main scenarios in Panel 1: (a) using our baseline parameters (Table 2),

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[25] Alternative values for λ^B, λ^S while keeping the sum $\tilde{\lambda}^S + \tilde{\lambda}^B$ unchanged yields similar implications for the aggregate welfare changes (Appendix Table F.2).

[26] Appendix Figure E.1 shows that the regression coefficients (in absolute terms) increase sharply around the estimated value of λ, indicating that the statistical uncertainty of the point estimate is small. These estimates of matching elasticities in firm-to-firm trade, including the feature of increasing returns to scale in matching ($\lambda^S = \lambda^B > 0.5$), align with findings from previous empirical studies (Miyauchi, 2024; Eaton et al., 2024).

and (b) shutting down endogenous networks ($\lambda^S = \lambda^B = 0$).[27] For the latter scenario, we keep the trade elasticity ε, averaged across the two destination sectors, at our baseline scenario. Column (1) reports the changes in aggregate welfare across all Chilean municipalities (weighted average of GDP changes across Chilean municipalities with pre-shock GDP weights); Column (2) reports the welfare gains from Column (1) relative to the values from the fixed network environment from row (b); Column (3) reports the average percent changes in imports from the U.S. and China; Column (4) reports the average changes in the number of supplier linkages from the U.S. and China; Column (5) reports the average changes in the number of supplier linkages within Chile.

Table 4: Aggregate Effects From Import Cost Increase From China and the U.S. (%)

	1) $\widehat{\text{Welfare}}$ (%)	2) Relative to Fixed Network	3) $\hat{X}_{ui,u\in\text{US,CN}}$	4) $\hat{M}_{ui,u\in\text{US,CN}}$	5) $\hat{M}_{ui,u\in\text{CL}}$
Panel 1: Baseline Calibration					
a) Endogenous Network	-0.88	1.6	-21.4	-8.3	-0.07
b) Fixed Network, fix ε	-0.56	1	-21.0	0	0
Panel 2: Sensitivity to Parameters					
c) Endogenous Network, $\gamma * 2$	-0.65	1.2	-20.9	-4.1	0.01
d) Endogenous Network, $\lambda/2$	-0.65	1.2	-21.0	-4.2	0.01
e) Endogenous Network, $\mu * 2$	-0.63	1.2	-21.3	-8.3	0.08
f) Endogenous Network, $\mu = 1$	-0.50	0.9	-21.2	-8.2	0.14

Notes: The results of counterfactual simulations to increase the iceberg trade costs from the U.S. and China to all Chilean municipalities by the same magnitude of the import tariff changes under the trade agreements used in Section 6.2 under two main scenarios in Panel 1: (a) using our baseline parameters (Table 2), and (b) shutting down endogenous networks, while keeping the trade elasticity ε, averaged across destination sectors, at our baseline scenario. In Panel 2, we explore sensitivity analysis with three alternative scenarios for the baseline model with endogenous networks: (c) increasing all γ^S, γ^B to twice their calibrated values, (d) reducing both λ^S and λ^B to its half, (e) increasing μ to twice its calibrated value ($\mu = 0.7$), and (f) increasing μ to $\mu = 1$. For rows (c)-(f), we also keep the trade elasticity ε, averaged across destination sectors, at our baseline scenario. Column (1) reports the changes in aggregate welfare across all Chilean municipalities (weighted average of GDP changes across Chilean municipalities with pre-shock GDP weights); Column (2) reports the ratio of the values in Column (1) to the alternative specification of fixed network (Row b); Column (3) reports the average percent changes in imports from the U.S. and China by Chilean municipalities; Column (4) reports the average changes in the number of supplier linkages from the U.S. and China; Column (5) reports the average changes in the number of supplier linkages within Chile.

Using our baseline specification, we find a 0.88 percent decline in Chile's aggregate welfare from the import cost increase (Column 1, Row a), indicating a modest but non-negligible aggregate welfare effect. These effects are associated with a decrease in aggregate imports from the U.S. and China by 21.4 percent (Column 3). More than a third of this decrease is attributed to the decrease in the extensive margin of Chilean import relationships from the U.S. and China

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[27] We calibrate the fixed-network environment using the same procedure described in Section 7.1, except that we impose $\lambda^S = \lambda^B = 0$ and take $\gamma^S, \gamma^B \to \infty$. Under our calibration, the total import-to-GDP ratio (i.e., the Domar weight of imports) is 24.1% in the baseline endogenous-network model and 22.3% in the fixed-network model, both very close to the 24.0% observed in the data.

(Column 4). We also find a reduction in supplier linkages within Chile (Column 5), consistent with the difference-in-differences evidence in Table 1.

In Row (b), we report the results of the counterfactual under the fixed-network environment. The aggregate welfare loss reduces to 0.56 percent. Thus, the endogenous network model generates welfare losses that are 60% larger relative to the fixed-network model. We also observe similar changes in import responses from the United States and China (Column 3), consistent with the assumption that both model versions share the same trade elasticities. By construction, production networks do not change (Columns 4 and 5).[28]

According to Proposition 2, whether allowing for endogenous network formation increases aggregate welfare effects, to a first order, depends on whether equilibrium trade flows are distorted upward or downward relative to the exogenous-network benchmark. As discussed earlier, the sign and magnitude of this distortion are determined by whether the private returns to relationship formation exceed the corresponding social returns, which in turn depend on the extent of imperfect competition and matching externalities. Under our calibration, these forces jointly generate a net downward distortion in equilibrium trade flows.

In Panel 2 of Table 4, we report sensitivity analyses using alternative parameter values. Doubling γ^S, γ^B or halving λ^S, λ^B yields smaller welfare changes relative to the baseline endogenous-network environment (Rows c and d). This pattern is consistent with Proposition 2: these parameters shift the gap between the social returns to relationships and the equilibrium private spending on relationship-formation effort.

We also find that doubling μ reduces welfare changes relative to the baseline (Row e). If we further increase μ to one, the welfare changes get similar and even smaller than in the fixed-network environment (Row f). This pattern again matches the prediction of Proposition 2. The gap of welfare changes in response to trade shocks between endogenous and fixed networks depends not only on how far relationship-formation effort departs from the social optimum, but also on the extent to which such effort generates extra demand for intermediate inputs, which depends on μ.

Increasing μ also alters the model's predictions for how domestic linkages respond to higher trade costs. In particular, a higher μ implies an expansion of domestic production linkages following a trade-cost increase (Row e, Column 5), whereas the baseline model predicts a contraction (Row a). Holding all else constant, a lower μ therefore helps reconcile the model with our difference-in-differences empirical finding that import tariff reductions strengthen domestic pro-

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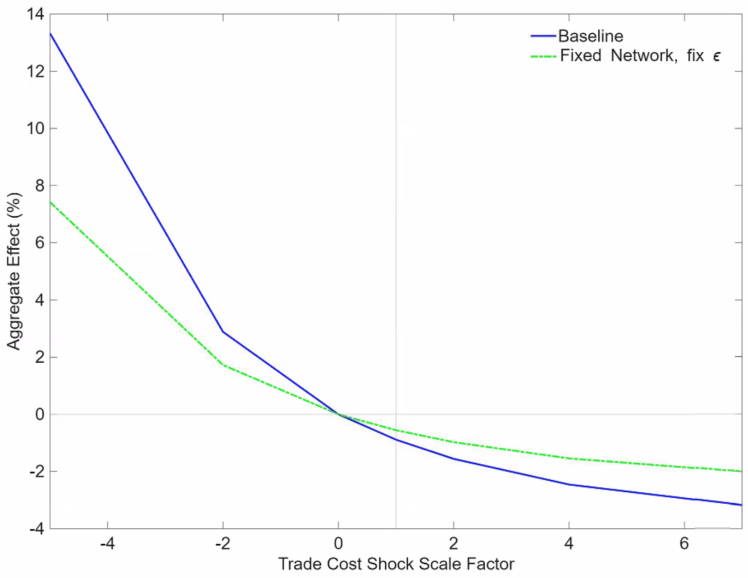
[28] Fixing the elasticity of substitution σ_k (instead of fixing trade elasticity) yields similar welfare loss and smaller changes in trade flows (Appendix Table F.1), consistent with the prediction of Proposition 2 that the trade elasticities do not affect aggregate welfare changes to a first order.

duction networks (Table 1).[29]

We turn to analyzing how these predictions change by the sign and the magnitude of the shock. In Figure 1, we report the aggregate welfare effects of the iceberg trade cost changes from the U.S. and China to all Chilean municipalities by the magnitude of reverting the trade agreements, multiplied by the value on the horizontal axis. A value of zero in the horizontal axis indicates no trade cost shock; a value of one indicates the same increase in the iceberg trade cost as in Table 4; a negative value indicates a decrease in the iceberg trade costs.

Figure 1: Aggregate Welfare Effects From Import Cost Change: Sign and Magnitude of the Shock



Notes: The figure shows the aggregate welfare effects of the iceberg trade cost changes from the U.S. and China to all Chilean municipalities by the magnitude of reverting the trade agreements, multiplied by the value on the horizontal axis. A value of zero in the horizontal axis indicates no trade cost shock; a value of one indicates the same increase in the iceberg trade cost as in Table 4; a negative value indicates a decrease in the iceberg trade costs. "Baseline" corresponds to our baseline endogenous network specification, and "Fixed network, fix ε" corresponds to the fixed network specification, corresponding to specifications (a) and (b) in Table 2.

As expected, aggregate welfare losses increase monotonically in the magnitude of the trade cost shock, both under the endogenous and fixed network environments. Welfare changes are consistently larger under endogenous networks, and the gap relative to the fixed-network case widens as the shock grows, especially for large reductions in trade costs. This pattern is consistent with the interpretation that a substantial trade cost declines trigger a reorganization of produc-

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[29] In Appendix Figure E.2, we also illustrate that a larger value of μ makes the model-predicted regression coefficients of the number of domestic suppliers on the exposure to trade shocks—used in calibrating λ in Section 7.1—less negative, turning positive when $\mu = 1$. This pattern aligns with the interpretation that when $\mu < 1$, higher international import costs lower the relationship-formation costs, thereby encouraging firms to add suppliers not only internationally but also domestically.

tion networks, generating higher-order effects beyond the first-order response.[30] In particular, through the multiplier effects of relationship-formation costs, regions experiencing trade-cost reductions expand their production linkages, thereby increasing surrounding trade flows. This mechanism amplifies the aggregate impact of trade shocks beyond their first-order effects.

7.3 Welfare Gains from Trade Relative to Autarky

We next examine how endogenous production networks shape the welfare effects of even larger trade-cost shocks—specifically, the gains from trade (GFT) relative to autarky. Quantifying GFT is a core question in international trade, and our analysis shows how allowing networks to adjust endogenously changes these welfare implications in important ways.

In Panel (a) of Table 5, we report the GFT relative to municipality autarky, i.e., average welfare changes by shutting down all trade with other Chilean municipalities and international countries. In Panel (b), we report the GFT from international autarky, i.e., the same values by shutting down all trade with international countries but keeping the trade within Chile across municipalities.

Starting from the GFT relative to municipality autarky (Table 5 (a)), we find an estimate of 401 percent using our baseline specification (Row a). When we shut down endogenous networks while keeping the trade elasticity ε fixed, GFT decreases to 191 percent. Thus, the welfare gains from trade allowing for endogenous production network formation are more than twice the welfare gains from trade under the exogenous network environment. This is consistent with Proposition 4: Fixing trade elasticities, GFT is larger through the relationship-formation cost multiplier.

Panel 2 of Table 5 (a) reports sensitivity analyses using alternative parameter values. Similarly to Panel 2 of Table 4, we find that increasing γ^S, γ^B, decreasing λ^S, λ^B, and increasing μ yield smaller welfare changes relative to the baseline endogenous-network environment. These patterns are consistent with the prediction of Proposition 4, where these parameters discipline the additional multiplier through relationship-formation costs (notice that we fix the values of trade elasticities ε throughout different model versions).[31]

We next discuss the GFT relative to international autarky, while allowing for domestic trade across municipalities within Chile (Table 5 (b)). The average GFT is 15.1 percent—an order of magnitude smaller than the gains relative to municipality autarky (Table 5 (a)) and closer to typical country-level estimates (Costinot and Rodríguez-Clare, 2014). Shutting down endogenous network formation while holding the trade elasticity ε fixed reduces GFT to 11.1 percent. Thus,

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[30] The second-order effects of trade cost shocks, applied to Proposition 3, is given by $-\frac{\varsigma}{\frac{\beta}{1-\beta}-\frac{1-\mu}{\sigma-1}\left(\tilde{\lambda}^B+\tilde{\lambda}^S\right)}\sum_{u,d} d\ln X_{ud} d\ln \tau_{ud}$.

[31] Because of sectoral reallocation, the gains from trade in the multi-sector model do not coincide between the exogenous and endogenous network environments when $\mu_k = 1$ as shown in Proposition C.2, unlike in the single-sector case in Proposition 4.

Table 5: Welfare Gains from Trade

(a) Relative to Municipality Autarky

	1) $\widehat{\text{Welfare}}$ (%)	2) Relative to Fixed Network
Panel 1: Baseline Calibration		
a) Endogenous Network	401	2.10
b) Fixed Network, fix ε	191	1
Panel 2: Sensitivity to Parameters		
c) Endogenous Network, $\gamma * 2$	241	1.26
d) Endogenous Network, $\lambda/2$	246	1.29
e) Endogenous Network, $\mu * 2$	205	1.07
f) Endogenous Network, $\mu = 1$	194	1.02

(b) Relative to International Autarky

	1) $\widehat{\text{Welfare}}$ (%)	2) Relative to Fixed Network
Panel 1: Baseline Calibration		
a) Endogenous Network	15.1	1.36
b) Fixed Network, fix ε	11.1	1
Panel 2: Sensitivity to Parameters		
c) Endogenous Network, $\gamma * 2$	12.6	1.14
d) Endogenous Network, $\lambda/2$	12.6	1.14
e) Endogenous Network, $\mu * 2$	11.3	1.02
f) Endogenous Network, $\mu = 1$	9.2	0.82

Notes: Panel (a) reports the welfare gains from trade relative to regional autarky by Chilean municipalities, i.e., average welfare changes by shutting down all trade with other Chilean municipalities and international countries. Panel (b) reports the same values by shutting down all trade with international countries but keeping the trade within Chile across municipalities. Rows (a)-(f) correspond to the same set of alternative model specifications as used in Table 2. For rows (b)-(f), we also keep the trade elasticity ε, averaged across destination sectors, at our baseline scenario (row a).

endogenous networks raise GFT by a factor of 1.36 in this comparison. Therefore, we again find a larger GFT, though the amplification is more modest than in the municipality-autarky case.

The contrast between the municipality- and international-autarky counterfactuals highlights the role of domestic network reorganization across Chilean municipalities. Under international autarky, firms can still reconfigure their domestic supplier relationships, and this flexibility partially offsets the amplification force. This mechanism aligns with the findings of Korovkin, Makarin and Miyauchi (2025), who examine how network reorganization shapes the aggregate impact of localized conflict shocks in Ukraine. Using an extension of our framework with richer firm heterogeneity, they show that allowing for endogenous networks mitigates the output decline from conflict-driven spillovers because firms can reorganize production networks in non-conflict areas.[32] More broadly, these comparisons suggest that the role of endogenous networks differs markedly depending on the nature of the trade shocks.

8 Conclusion

We study the aggregate implications of endogenous production network formation in a quantitative multi-location general equilibrium trade model. We develop sufficient statistics formulas for global and each region's welfare and characterize the precise deviation from the fixed network environment. The deviation occurs due to inefficiency for the *ex-ante* welfare sufficient statistics, and due to the differences in trade elasticities and the multiplier effects from relationship-formation costs for the *ex-post* welfare sufficient statistics. We also provide macro restrictions under which these sufficient statistics hold for any microfoundation of production network formation, providing a coherent account of how and why endogenous production network formation matters for aggregate welfare. Calibrating the model to Chilean firm-to-firm trade data, in particular to how production network formation responds to a trade liberalization, we find that endogenous networks increase welfare effects of small trade-cost shocks—due to inefficiently low pre-shock linkages—and the welfare gains from trade relative to municipality autarky—due to amplification effects through network formation.

More broadly, our analysis provides a systematic framework for studying aggregate trade shocks in an environment where trade structure evolves endogenously through firms' investment decisions. We show that those endogenous decisions shape aggregate welfare effects through three key forces: equilibrium inefficiencies, trade elasticities, and the multiplier effects of the investment costs.

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[32] In their fixed-network counterfactual, they also hold the elasticity of substitution σ_k constant, implying a lower trade elasticity.

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