Essays on Innovation and Technology Diffusion with Interdependent Market Entry

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Contents

Abstract

In this thesis, I emphasize the role of spatial linkages as well as market interaction by examining how local technology shocks affect the aggregate economy and how interdependent market entry affects firm-specific choices and welfare. Interdependence means that market-specific choices for one market depend on characteristics from all other markets. In a collection of three research papers, I analyze (i) the characteristics of key regions in the German economy, (ii) the impact of price integration on heterogeneous firms and the aggregate economy, and (iii) the effects of market interdependence, captured by firm-specific technology investments and affecting firm-specific productivity for all destination markets, on firm-specific choices and welfare.

In the first essay, I use a spatial Ricardian model to characterize the key regions in the German economy, which are defined to have the largest aggregate effect on respectively, productivity, real GDP, and welfare. Given the current structure of the German production network, local productivity growth in the most productive regions, like Munich and Hamburg, does not maximize the outcome of the aggregate economy as they are already too congested. The key regions are central in the production network with tight connections in terms of input-output linkages and intra-national trade. Yet, they have a low degree of initial labor congestion. Further, I find that in the period between 2010 and 2015, the largest productivity gains have not been achieved by the key regions themselves, which implies that the German economy has developed below its potential.

The second essay evaluates the impact of price integration on firm-specific choices and, in the context of trade liberalization, on the resulting welfare gains. Every firm charges one price for all markets. The results show that firms charge lower prices, are less likely to export, and earn lower aggregate expected profits compared to perfectly segmented markets. In exogenous scenarios of trade liberalization, the respective welfare gains are larger for integrated markets. This effect is the result of a lower initial welfare level for integrated markets and a stronger competition for the limited supply of labor given the restrictions in the ability to set optimal prices.

In the third essay, I study how interdependent market entry, created by a single firm-specific innovation affects firms' choices and welfare. The main finding is that trade liberalization leads to higher welfare gains for integrated markets than for a setting with market-specific investment. The result is driven by higher investment levels when firms optimize aggregate profits. The respective welfare gains are decreasing in the investment returns and increase in the number of destination markets. Investment returns positively affect firms in their investment level, market entry, and aggregate profits. On the other hand, a higher number of markets reduces the market size and therefore, lowers technology adoption and market entry probabilities for a constant aggregate market size.

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1 Introduction

During the last decades, the world has become more integrated and globalized. In the period between 1945 and today, trade costs and quotas have substantially declined, markets have become increasingly transparent, and the overall efficiency of serving foreign markets with open borders has led to a tremendous degree of market integration. For example, relative to the 2000s, trade costs in the European Union have been estimated to be 45% higher in the 1960s (see Levchenko and Zhang, 2012). Part of the efficiency rise can be attributed to increasing technology levels and the transfer of more advanced technology across borders, which leads to a complex interaction of markets in the global context.

A similar interaction is observable within the national borders of Germany, where locations with strong spatial linkages such as Munich and Hamburg constitute important economic centers with a high level of productivity. Meanwhile, wide parts of the rural Germany are less productive. This spatial heterogeneity is attributable to spatial networks, in particular, to input-output linkages, intra-national trade relationships, income redistribution, and the reallocation of labor. For example, labor mobility is the result of differences in technology and resulting in wage differences, thus contributing to further spatial heterogeneity.

Both perspectives share that as a result of their complex interactions, analyzing economic activity must account for the corresponding linkages and the degree of market integration. Both the presence and strength of spillovers are important issues for policymakers, in particular when allocating subsidies to regions and sectors, thereby targeting those locations with the highest potential in affecting the aggregate economy.

This thesis aims to bridge the gap to the literature, which still misses incorporating important linkages both within the national economy and across borders. In my thesis, I combine a spatial analysis to identify the German key regions with extended heterogeneous firm models to evaluate how (i) a single-pricing scheme for all markets, and (ii) a single innovation choice, respectively, affect individual firms and the aggregate economy in terms of welfare. Besides addressing the specific research questions, I also provide a methodological contribution suggesting a solution mechanism to estimate models with interdependent market entry.

The second chapter of this thesis is joint work with Marcel Henkel. We highlight the role of disaggregated productivity shocks in the spatial development and identify the set of key regions in Germany with the highest potential to affect the economy in terms of measured total factor productivity (TFP), real GDP, and welfare.

Using rich and disaggregated data for intra-national trade and input-output relations, we identify the set of regions with the strongest spatial linkages. To be precise, we first use a region-specific hypothetical 10% shock on each region's fundamental productivity to rank the locations according to the resulting aggregated changes in either measured TFP, real GDP, or welfare. Our main finding is that given the current structure of the German production network, local productivity growth in the most productive regions, like Munich and Hamburg, does not maximize the outcome of the aggregate economy as they are already too congested. Rather, key regions are central in the economic network with tight connections in terms of input-output linkages and intra-national trade but not too congested.

In a subsequent exercise, we evaluate if these key regions have also contributed most to the actual development in measured TFP, real GDP, and welfare. We, therefore, combine the model structure with detailed data on real wages and employment to approximate the actual productivity changes in the period between 2010 and 2015. Our results show that the key regions have experienced a rather modest development in productivity, and that if the key regions had experienced the growth rate of the top performers, output, and welfare could have been higher by a factor of two.

Chapters 3 and 4 are based on a current research agenda that has been developed by Tobias Seidel and Sergey Nigai and has been granted funding from the "Deutsche Forschungsgemeinschaft" (DFG, grant no. SE 1893/2-1). The idea of the research agenda is based on methodological issues when modeling interdependent market entry. To capture so-called market integration, we enforce firms to set one price for all markets, making this price a function of income, bilateral trade costs, and wages from all markets. Further, pricing depends on market entry, which is usually binary, i.e., firms either export or not. This leads to numerical problems in the presence of J countries, given the requirement to compare 2^J combinations when identifying the optimal firm structure. To circumvent this issue, we introduce stochastic fixed costs, which imply a probabilistic market entry structure and lead to a continuous objective function with well-defined first-order conditions.

In the third chapter, I use this heterogeneous firm model to analyze how price integration affects firm-specific decisions and welfare in the presence of trade liberalization. The idea that firms set a single price for different markets has applications both in the national as well as international context.

For example, DellaVigna and Gentzkow (2019) argue that firms have incentives to charge a single price for different markets within national borders to avoid menu costs and consumer-induced substitution. In the international context, there is empirical evidence for a starting convergence in prices across borders, which can be explained by increasing integration of markets in economic unions (see Ilzkovitz et al., 2007) and the increasingly difficulty of observing cross-border arbitrage after introducing the common currency euro in the European Monetary Union (Méjean and Schwellnus, 2009). Third, there are institutional restrictions in the price-setting behavior of firms, for example, the existing fixed book price agreements. According to this law, which exists in numerous European countries (e.g., Germany, Austria, France), publishers are allowed to determine the price at which bookshops must sell the book within borders.

Based on this evidence, I use a heterogeneous firm model to evaluate how the single-pricing rule affects firms differing in their productivity level. The benefit compared to the seminal model pioneered by Melitz (2003) is to study price integration but to maintain empirically observable trade frictions.

An additional contribution is the assumption of stochastic fixed costs to obtain a continuous objective function with well-defined first-order conditions. This leads to a probabilistic notion of the export choice. The results show that compared to pricing-to-market, firms charge lower prices, are less likely to export, and earn lower aggregate profits. The differences are increasing in the trade cost level and more pronounced in particular for low-productivity firms. Further, I evaluate the welfare changes of exogenous trade cost changes and compare the results for the single-pricing to those under price discrimination. In the main specification, a 10% decline in trade costs lead to welfare gains of 4.89% for integrated markets and 4.33% for segmented markets, respectively. The mechanism can be summarized as follows. Given the potential market entry of low-productivity firms, there is an increase in the demand for labor and hence, an increase in the real wage given that labor is the only input factor. This leads to larger percentage gains for integrated markets given the lower initial level. The observed patterns are robust to changes in the number of markets, across different fixed costs, and to a setting with partial integration, i.e., when the single-pricing applies only to a subset of markets.

In the fourth chapter, I study how firm-specific choices and aggregate welfare are affected in a heterogeneous firm model with multiple countries and market interdependence. To model market interdependence, I assume that firms choose an optimal innovation level to raise effective productivity and lower marginal production costs for all markets. In this way, the optimal pricing choice and the entry decision for one market depend — via the interdependent innovation choice — on characteristics from all markets. Similar to the model used in chapter 3, stochastic fixed costs ensure a continuous objective function that delivers well-defined first-order conditions to solve the model for an arbitrary number of markets.

The main finding of the empirical exercise is that trade liberalization leads to higher welfare gains for integrated markets than under segmentation when firms choose market-specific investment levels. Intuitively, firms choose higher aggregate investment levels for segmented markets. However, the larger overall spending is divided across markets leading to lower market-specific shares compared to the single investment where the given investment can be used for all markets. This result is robust across different investment returns and for different degrees of market interdependence, captured by variable numbers of markets.

To derive this finding, I first show that there is a positive relationship between the investment returns and the investment level, the export probability, and expected aggregate profits. On the other hand, firms charge lower market-specific prices. The investment choice leads to a shift of resources to high-productivity firms, which increases the inequality in expected aggregate profits. Second, I evaluate the strength of interdependence by increasing the number of markets while holding constant the aggregate market size. The decreasing labor force strengthens the competition for labor, thus, lowering investment levels and market entry probabilities. On the other hand, firms charge higher prices. The negative effects dominate the benefits of serving a larger number of export destinations.

Finally, I combine these insights when quantifying the welfare gains from trade liberalization and comparing integrated markets to segmented markets. Segmentation allows for market-specific investments and thus serves as a reference. I find higher welfare gains for integrated markets, where in the baseline case with $J = 4$ markets, the gains vary between 1.55% and 1.59% for integrated markets, and between 1.05% and 1.09% for segmented markets, depending on the investment returns. The difference is driven by a larger investment level available to each market under integration compared to market-specific innovation. For zero-returns, the welfare gains of 1.86% are identical for the two settings and higher than for positive returns. The welfare gains are decreasing in the investment returns, but increasing in the magnitude of trade liberalization, and the number of markets.

2 The Role of Key Regions in Spatial Development

Abstract

We discuss the role of key regions in spatial development. Local productivity shocks can affect the entire economy as they expand via tight connections in the domestic production network and influence the geographical allocation of labor. In particular, we identify the set of key regions with the highest potential to affect aggregate productivity, output, and welfare. Key regions are central locations with strong spatial linkages in the production network but are not too large and congested so they can still attract additional labor in response to positive productivity shocks without local rents and input costs rising too much. Using a spatial equilibrium model and data from German districts, we find that a relatively modest development of productivity in key regions lowered German output and welfare growth by a factor of two from 2010 to 2015.

2.1 Introduction

Large cities constitute the economic centers of each economy attracting the most productive workers and firms. This goes along with considerable differences in income per capita between cities and rural areas in many countries. In Germany, for example, productive cities like Munich and Hamburg have more than twice the income per capita than rural areas and smaller cities. At the same time, however, small towns and cities often host important suppliers providing specialized materials, components, and services to the rest of the economy.

A larger presence of highly specialized intermediate goods suppliers allows local firms to concentrate on what they are relatively good at producing without having to devote resources to other functions. As this represents an important source of competitive advantage, this increases local income and productivity levels and provides incentives for firms and workers to agglomerate in or close to geographical areas with stronger input-output linkages between highly specialized firms (Krugman and Venables, 1995, Moretti, 2011). If the strength of input-output linkages and with it the productivity of firms and workers varies considerably across space, the aggregate economy can, in general, be stimulated by facilitating local productivity and expanding employment in so-called key economic regions via spatial development policies, for example, in the form of public investments, subsidies, or enterprise zones.[1] Moreover, recent research suggests that local shocks hitting important suppliers can amplify via tight connections in the network of input-output and trade linkages (e.g., Adao et al., 2019) with the potential to affect the entire economy (Gabaix, 2011; Carvalho, 2014). This suggests that spatial development is particularly promising in areas with existing clusters of specialized intermediate goods suppliers and strong input-output linkages such that local productivity shocks in a particular sector there spread through the wider economy (Redding and Rossi-Hansberg, 2017).

We argue that while positive local productivity growth and economic development are beneficial for the local economy, it may be less so for the aggregate when it diverts economic activity away from key economic regions (Kline and Moretti, 2014; Hsieh and Moretti, 2019). In Germany, the government redistributes substantial public resources across regions and creates a

[1] See Neumark and Simpson (2015) for a comprehensive survey.

variety of spatial development policies in the form of public investments and subsidies. A remarkable total amount of 65.7 billion euro worth of transfers are shifted across regions and around 1.5 billion euro are spent on spatially targeted development policies per year (Henkel et al., 2019). Given all these big efforts we do not know, however, where are the best places to promote spatial development if the government wants to maximize aggregate productivity, output, and welfare?

In this paper, we identify the key regions with the highest potential to affect the German economy. Specifically, we follow Caliendo et al. (2018) and quantify a spatial variant of a general equilibrium model to analyze the long-term aggregate changes in total factor productivity (TFP), real gross domestic product (real GDP), and welfare allowing for the endogenous reallocation of labor and adjustment of prices in response to local productivity growth. We employ a unique dataset on interregional trade relations and input-output linkages between sectors while taking any initial differences in size and economic importance between regions into account. In a counterfactual analysis, we then simulate how aggregate economic activity and the distribution of workers and income across space would change in response to a spatial development policy measured by an exogenous increase in local productivity in all tradable and non-tradable sectors of a region. We repeat this exercise for all regions and compare the aggregate effects.

The main finding of the analysis is that the growth rate of aggregate productivity, output, and welfare is not necessarily maximized by concentrating local productivity growth in the most productive regions. In other words, given the current production structure in Germany, the most productive cities do not serve as the key regions in spatial development. If the government wants to maximize aggregate economic outcome, when allocating local productivity growth across regions, it should target central, but less congested regions in the vicinity of large cities.

The regional allocation of local productivity growth via spatial development policies affects the aggregate economy through a complex mechanism. Any increase in a region's local productivity raises local wages and employment but is not restricted to the affected region or sector as it is transmitted to other regions and sectors via spatial links (measured by input-output and trade linkages) in the economy. Changes in relative prices affect trade patterns and the real income of workers in each region. This provides incentives for workers to migrate between regions, which further affects the level of productivity, real income, and welfare. Local rents, however, increase in response to an influx of labor, as some local production factors, like land and existing structures (machinery, equipment, etc.), are in fixed supply. Higher nominal wages and rental prices lead to higher local input costs acting as a congestion force and constraining the potential of further economic growth. If the most productive cities are not too congested, then less productive regions are not the best places for spatial development programs. In this case, increasing productivity in the largest and most productive cities is good for economic growth due to strong spatial links and the high presence of important suppliers there. But if the less congested and productive regions are still relatively central in the domestic production network, then it pays off to concentrate local productivity growth in initially smaller regions.

Further, we quantify the aggregate effects based on observed local productivity changes in Germany. While cities like Berlin and Munich (Frankfurt am Main and Cologne) had a major impact on aggregate output (welfare) growth between 2010 and 2015, the key regions contributed significantly less due to relatively low local productivity growth there. We interpret this as a sign of a (relatively) poor performance of the German economy compared to its potential optimum, in terms of both real GDP and welfare. In Germany, highly productive cities attracted the largest share of employment between 2010 and 2015, while productivity and employment growth in less congested key regions with strong spatial linkages was less pronounced. To quantify the magnitude of this finding, we consider what would have happened if the key regions in Germany had experienced the highest observed local productivity changes. When we assign local productivity changes according to each region's theoretical potential to affect the aggregate economy we find growth rates of aggregate productivity, output, and welfare that are twice as large as in a baseline scenario that accounts for the actual observed productivity changes. We conclude that a low economic performance of the key regions of an economy and too much concentration of economic activity in already congested areas can have sizeable implications for aggregate growth. In our case, a relatively low local productivity growth in key regions lowered German output and welfare growth by a factor of two from 2010 to 2015.

Our paper relates to various strands of literature. First, we build on the general idea of the literature on the macroeconomic importance of local shocks in production networks, where local shocks do not necessarily wash out and potentially affect the aggregate economy when they hit an important supplier.[2] We demonstrate how local shocks propagate through the entire production network via input-output and trade linkages. Similar to this strand of literature so-called "cascade effects" in the production network have the potential to amplify the impact of initial small local shocks.[3] Our paper builds on this general idea showing that local productivity shocks in more central but less congested regions have the largest potential to affect the aggregate economy and to attract economic activity in the long-run. We differ from this work by highlighting how the aggregate effects of local productivity changes depend on the mobility of labor across regions and sectors. Second, we build on the work that uses quantitative general equilibrium models with labor mobility to analyze the spatial distribution of economic activity within countries.[4] An important aspect of these models is that they account in their analysis of the aggregate impact of a local TFP shock for all spillover effects, through spatial linkages and the mobility of labor, to all other regions. We follow Caliendo et al. (2018) who introduce the detailed structure of trade and input-output networks as spatial linkages into a quantitative economic geography model to analyze the impact of regional and sectoral productivity changes across US federal states. Our focus is to analyze, in the spirit of Rahman (1963), how to allocate local productivity growth via spatial development policies across regions to maximize aggregate economic outcomes. To our knowledge, this is the first paper to identify the key regions of the German economy while simultaneously accounting for the disaggregated production structure.

The paper is organized as follows. Section 2.2 describes the model and discusses the model-induced channels. Section 2.3 presents the data and the calibration of the model to the data. In Section 2.4, we identify the key regions for the aggregate economy. Finally, we evaluate the impact of observed local productivity changes on the aggregate economy. Section 2.5 concludes.

2.2 A spatial model with input-output linkages

We use a spatial general equilibrium model with input-output linkages (see, e.g., Caliendo et al., 2018). Consider an economy with N regions (indexed by i, n) and J sectors or goods (indexed by j, k). Production takes place under conditions of perfect competition and constant returns to scale. The economy is populated by a mass of $\bar{L}$ workers, who are mobile across regions and sectors. Each region is endowed with a limited amount of a geographically immobile factor comprising land and structures, which is mobile across sectors. In each region and sector representative firms use labor L_n^j and land and structures H_n^j to produce intermediate goods q_n^j. Productivity levels differ across firms, sectors, and regions.

Intermediate goods from a given sector j may be either shipped between any two regions i and n at iceberg trade costs $\kappa_{ni}^j \geq 1$, or non traded with $\kappa_{ni}^j = \infty$ for all $i \neq n$. Intra-regional trade costs, κ_{ii}^j, are normalized to unity. Firms in region n and sector j use the intermediate goods to produce non-traded final goods Q_n^j. Further, final goods of each sector are either consumed by representative agents or enter again the production process of intermediate goods in all industries as additional material inputs.

[2]See, for example, Horvath (1998, 2000); Baqaee (2018); Baqaee and Farhi (2019); Di Giovanni and Levchenko (2010); Gabaix (2011); Bigio and La'O (2016).

[3]See, for example, Acemoglu et al. (2012), Acemoglu et al. (2015) and Acemoglu et al. (2016).

[4]See Redding and Rossi-Hansberg (2017) for a recent survey.

2.2.1 Preferences

In each region n, consumers derive utility from the consumption of final domestic goods c_n^j and supply inelastically one unit of labor. Workers generate income I_n from wages w_n and the returns from land and structures, r_n. Local governments partly own the local factor land and structures and collect a share $(1-\iota_n)$ of region n's local rents. The local government redistributes the corresponding revenues to residents in a lump-sum fashion. The remaining fraction of the rents of the local factor ι_n goes into a national portfolio and all workers of the economy receive the same proportion of its returns. The preferences of workers are represented by a utility function of Cobb-Douglas type, where the consumption shares $\sum_{j=1}^{J}\alpha^j = 1$ vary across sectors. To maximize utility the budget-constrained representative workers choose consumption bundles c_n^j at prices P_n^j in all sectors $j \in \{1, ..., J\}$ according to:

$$U_n \equiv \max_{\{c_n^j\}_{j=1}^J} \prod_{j=1}^{J} (c_n^j)^{\alpha^j} \quad \text{subject to} \quad \sum_{j=1}^{J} P_n^j c_n^j = I_n, \tag{1}$$

where $I_n = w_n + (1-\iota_n) r_n H_n / L_n + (\sum_{i=1}^{N} \iota_i r_i H_i / \sum_{i=1}^{N} L_i) L_n$ is the per capita income of agents in region n and P_n^j denotes the price of a sector $j's$ output in region n. $P_n = \prod_{j=1}^{J} (P_n^j/\alpha^j)^{\alpha^j}$ denotes the region-specific price index.

2.2.2 Production technology

Representative firms produce a continuum of varieties with constant returns to scale technologies. In any region n and sector j representative firms use labor as well as land and structures, and potentially final goods from any other sector k as 'material' inputs.

Productivity. Firms of any region n and sector j differ in their idiosyncratic productivity level $z_n^j > 0$. Across all goods, sectors, and regions the idiosyncratic productivity levels are independently drawn from a Fréchet distribution such that the joint density function is given by:

$$\phi^j(z^j) = \exp\left\{ -\sum_{i=1}^{N} \left(z_n^j\right)^{-\theta^j} \right\}, \tag{2}$$

with productivity draws $z^j = (z_1^j, \ldots, z_N^j)$, a location parameter of 1 and sector-specific shape parameters $\theta^j > 1$. The shape parameter, θ^j, captures the extent of sector-specific heterogeneity in technological know-how across varieties and is assumed to be constant across goods and regions. A larger θ^j implies less variability across goods and regions. Production depends also on the non-random fundamental productivity level T_n^j. The level of fundamental productivity aims to capture factors that affect the productivity of all firms in a given region and sector. For example, local climate, infrastructure, and regulation.[5]

Intermediate goods. The production function for the intermediate good $q_n^j(z_n^j)$ in region n and sector j is Cobb-Douglas:

$$q_n^j(z_n^j) = z_n^j \left[T_n^j \left[h_n^j(z_n^j)\right]^{\beta_n} \left[l_n^j(z_n^j)\right]^{1-\beta_n} \right]^{\gamma_n^j} \prod_{k=1}^{J} \left[M_n^{jk}(z_n^j) \right]^{\gamma_n^{jk}}, \tag{3}$$

[5] Alternatively, to model region-sector-specific productivity differences we could set the location parameter of the joint density function to $(T_n^j)^{\beta_n}$. This, however, would imply a disproportional increase of real GDP in response to fundamental productivity shocks.

where $h_n^j(\cdot)$ and $l_n^j(\cdot)$ reflect the demand for land and labor, respectively, β_n is the share of land and structures in value-added, $M_n^{jk}(\cdot)$ is the demand for final goods from sector k used in the intermediate goods production of sector j (materials), γ_n^j denotes the share of value-added in gross output and γ_n^{jk} represents the share of sector j goods spent on materials from sector k. Because of constant returns to scale, it must hold $\gamma_n^j = 1 - \sum_{k=1}^J \gamma_n^{jk}$.

Market structure. Markets are assumed to be perfectly competitive. There is free entry of firms implying zero profits. The cost of the input bundle required to produce intermediate goods in region n and sector j is given by:

$$x_n^j = B_n^j \left[r_n^{\beta_n} w_n^{1-\beta_n} \right]^{\gamma_n^j} \prod_{k=1}^{J} \left[P_n^k \right]^{\gamma_n^{jk}}, \tag{4}$$

with the region-sector-specific scaling factor $B_n^j = [\gamma_n^j (1-\beta_n)^{1-\beta_n} \beta_n^{\beta_n}]^{-\gamma_n^j} \prod_{k=1}^{j} [\gamma_n^{jk}]^{-\gamma_n^{jk}}$, and P_n^k is the price index for intermediate goods in region n and sector k. Assuming constant returns to scale, the unit cost is $x_n^j / (z_n^j [T_n^j]^{\gamma_n^j})$. Firms in region n and sector j will set their prices according to their unit costs.

Interregional trade. Intermediate goods trade between any regions n and i within a given sector j is costly. Trade costs $\kappa_{ni}^j \geq 1$ are of the iceberg type. Hence, $\kappa_{ni}^j \geq 1$ units of an intermediate good must be shipped from location i to location $n \neq i$ in sector j for one unit to arrive. Perfect competition together with constant returns to scale imply that agents in each region n aim to minimize the cost of acquiring a specific intermediate good in sector j. The trade cost-adjusted price p_n^j across all potential source regions is given by:

$$p_n^j(z_n^j) = \min_i \left\{ \frac{\kappa_{ni}^j x_i^j}{z_i^j} (T_i^j)^{-\gamma_i^j} \right\}, \tag{5}$$

with the input costs x_i^j, trade costs κ_{ni}^j, and the two productivity terms T_i^j and z_i^j, scaled by the share of value-added in gross output γ_i^j. The price of a tradable sector $j's$ output in region n is given by:

$$P_n^j = \Gamma(\varphi_n^j)^{1-\eta_n^j} \left(\sum_i \left(x_i^j \kappa_{ni}^j \right)^{-\theta^j} \left(T_i^j \right)^{\theta^j \gamma_i^j} \right)^{-1/\theta^j}, \tag{6}$$

where $\Gamma(\varphi_n^j)$ evaluates a Gamma function at $\varphi_n^j = 1 + (1-\eta_n^j)/\theta^j$.[6] The price of a non-tradable sector $j's$ output in region n is given by:

$$P_n^j = \Gamma(\varphi_n^j)^{1-\eta_n^j} x_n^j [T_n^j]^{-\gamma_n^j}. \tag{7}$$

In line with Alvarez and Lucas (2007), the expenditure share π_{ni}^j of region n on products from region i in sector j can be written as:

$$\pi_{ni}^j = \frac{X_{ni}^j}{\sum_{i=1}^N X_{ni}^j} = \frac{\left[\kappa_{ni}^j x_i^j (T_i^j)^{-\gamma_i^j} \right]^{-\theta^j}}{\sum_{i=1}^N [\kappa_{ni}^j x_i^j]^{-\theta^j} (T_i^j)^{\gamma_i^j \theta^j}}, \tag{8}$$

where the shape parameters $\theta^j > 1$ can be interpreted as the sector-specific trade elasticity.

[6] $\Gamma(\cdot)$ denotes the gamma function, i.e., $\Gamma(t) = \int_0^\infty u^{t-1} \exp(-u) du$.

Final Goods. Denote by $\tilde{q}_n^j(z^j)$ the quantity demanded of intermediates with productivity draws $z^j = (z_1^j, \ldots, z_N^j)$. Final goods in region n and sector j, Q_n^j, are produced using a 'Constant Elasticity of Substitution' (CES) production function that aggregates a continuum of varieties:

$$Q_n^j = \left(\int \tilde{q}_n^j(z^j)^{1-1/\eta_n^j} \phi^j(z^j) dz^j \right)^{\frac{\eta_n^j}{\eta_n^j - 1}}, \tag{9}$$

where η_n^j denotes the elasticity of substitution across varieties. For non-traded goods, only the region-sector-specific density function $\phi_n^j(z_n^j)$ is relevant because interregional trade is ruled out by construction.

2.2.3 Equilibrium

A competitive equilibrium in this economy is defined by the following conditions:

- **Labor market clearing.** This implies

$$L_n = \sum_{j=1}^{J} L_n^j = \sum_{j=1}^{J} \int_0^\infty l_n^j(z) \phi_n^j(z) dz \qquad \forall n = 1, \ldots, N. \tag{10}$$

  On the aggregate level, $\sum_{n=1}^{N} L_n = \bar{L}$, where total labor is normalized to one. Profit maximization together with labor market clearing yields $r_n H_n (1 - \beta_n) = \beta_n w_n L_n$.

- **Land and structures market clearing.** This implies

$$H_n = \sum_{j=1}^{J} H_n^j = \sum_{j=1}^{J} \int_0^\infty h_n^j(z) \phi_n^j(z) dz \qquad \forall n = 1, \ldots, N. \tag{11}$$

- **Final goods market clearing.** In equilibrium all final goods Q_n^j are used for consumption and intermediate goods production, so

$$Q_n^j = L_n c_n^j + \sum_{k=1}^{J} M_n^{kj} = L_n c_n^j + \sum_{k=1}^{J} \int_0^\infty M_n^{kj}(z) \phi_n^k(z) dz. \tag{12}$$

  Moreover, in equilibrium, the value of the final good j in region n sold to all destinations is equal to

$$X_n^j = \sum_{k=1}^{J} \gamma_n^{kj} \sum_i \pi_{in}^k X_i^k + \alpha^j I_n L_n, \tag{13}$$

- **Intermediate goods market clearing.** In equilibrium, total expenditures on intermediates purchased from other regions must equal total revenue from intermediates sold to other regions plus the net receipts from the national portfolio.

$$\sum_{j=1}^{J} \sum_{i=1}^{N} \pi_{ni}^j X_n^j + \Gamma_n = \sum_{j=1}^{J} \sum_{i=1}^{N} \pi_{in}^j X_i^j. \tag{14}$$

The difference between contributions and receipts from the national portfolio generates trade imbalances for region n given by:

$$\Gamma_n = \iota_n r_n H_n - \frac{\sum_{i=1}^{N} \iota_i r_i H_i}{\sum_{i=1}^{N} L_i} L_n. \tag{15}$$

This redistribution mechanism endogenizes trade surpluses and deficits in the model and aims to closely match trade imbalances Γ_n between regions observed in the data. A region n that is a net contributor to the national portfolio runs a trade surplus, while a net recipient runs a trade deficit.

- **Utility equalization.** Finally, free mobility of labor implies that agents must be indifferent about living in any region n.

$$v_n = \frac{I_n}{P_n} = U \;\; \forall n \in N. \tag{16}$$

The free mobility condition of labor together with labour market clearing, and $\omega_n = [r_n/\beta_n]^{\beta_n}[w_n/(1-\beta_n)]^{1-\beta_n}$, and $u_n = \iota_n r_n H_n / L_n - \chi$ leads in equilibrium to the labor demand equation:

$$L_n = \frac{H_n \left[\frac{\omega_n}{P_n U + u_n}\right]^{1/\beta_n}}{\sum_i H_i \left[\frac{\omega_i}{P_i U + u_i}\right]^{1/\beta_i}} L, \tag{17}$$

where, $\chi = \sum_i \iota_i r_i H_i / \sum_i L_i$ denotes the per capita receipts from the national portfolio.[7]

2.2.4 How changes in local productivity affect the spatial economy

In this section, we present the intuition of how changes in local productivity affect the spatial economy. From the structure of the model we derive analytic expressions for relative changes, $\hat{x} = x'/x$, in measured TFP, real GDP, and welfare, where x' denotes the new value. Input-output and trade linkages define how changes in local productivity diffuse across sectors and regions. The mobility of labor across regions and sectors as well as transfers of rental income across regions serve as additional adjustment channels. Derivations are in Appendix 2.B.

The structure of the model allows us to relate changes in measured productivity, $\hat{A}_n^j$, to fundamental productivity changes, $\hat{T}_n^j$, according to the following log-linear relationship:

$$\ln\left(\hat{A}_n^j\right) = \ln\left(\frac{\hat{x}_n^j}{\hat{P}_n^j}\right) = \ln\left(\frac{\left[\hat{T}_n^j\right]^{\gamma_n^j}}{\left[\hat{\pi}_{nn}^j\right]^{1/\theta^j}}\right). \tag{18}$$

The share of value-added in gross output, γ_n^j, adjustments of the home expenditure share, $\hat{\pi}_{nn}^j$, together with the trade elasticity, θ^j, scale changes in fundamental productivity.[8] For the growth of real GDP, we have:

[7] We present the equilibrium conditions in changes as well as the different steps of the solution mechanism in Appendix 2.A.

[8] Note that the share of value-added in output, γ_n^j, is a mirror image of the share of sector j goods spent on materials from sector k. Constant returns to scale in the intermediate goods production ensures that $\gamma_n^j = 1 - \sum_{k=1}^{J} \gamma_n^{jk}$.

$$\ln\left(\widehat{\mathrm{GDP}}_n^j\right) = \ln\left(\hat{A}_n^j\right) + \ln\left(\hat{L}_n^j\right) + \ln\left(\frac{\hat{w}_n}{\hat{x}_n^j}\right). \tag{19}$$

In addition to changes in measured productivity, $\hat{A}_n^j$, changes in labor, $\hat{L}_n^j$, and nominal wages relative to input costs, $\hat{w}_n/\hat{x}_n^j$, are important drivers for changes in real GDP. The change in welfare is given by:

$$\ln\left(\hat{U}\right) = \sum_{j=1}^{J} \alpha^j \left(\ln\left(\hat{A}_n^j\right) + \ln\left(\bar{\omega}_n \frac{\hat{w}_n}{\hat{x}_n^j} + (1-\bar{\omega}_n)\frac{\hat{\chi}}{\hat{x}_n^j}\right)\right), \tag{20}$$

with $\bar{\omega}_n = (1-\beta_n\iota_n)w_n / \left[(1-\beta_n\iota_n)w_n + (1-\beta_n)\chi\right]$. Hence, changes in measured TFP, nominal wages relative to input costs, and receipts per capita from the national portfolio relative to input costs, $\hat{\chi}/\hat{x}_n^j$, are important drivers for changes in welfare.

Input-output linkages. In region n and sector j, final goods of any other sector k may serve as potential additional input in the production of intermediate goods. These input-output linkages determine how changes in fundamental productivity in any region-sector pair n, j diffuse to other region-sector pairs $n, k \neq j$. The first component of the numerator in equation (18) highlights the importance of the input-output linkages for changes in measured TFP. The direct effect of fundamental productivity changes, $\hat{T}_n^j$, is scaled down by the share of value-added in gross output, γ_n^j. When input-output linkages are present, the share of value-added is less than one, $\gamma_n^j < 1$, and the direct effect is less than proportional. The rationale is that production in sector j then uses materials from other sectors $k \neq j$, which did not experience productivity improvements. Without any linkages between sectors $\gamma_n^j = 1$, a rise in fundamental productivity T_n^j would lead, everything else equal, to a proportional rise in measured productivity $\hat{A}_n^j$.

Trade linkages. Intermediate goods are traded within sectors across regions. In the Ricardian setting at hand, regions produce and export more intermediate goods in sectors in which they are relatively more productive. The relative level of fundamental productivity determines the comparative advantage in producing and exporting of each region with each sector. A positive fundamental productivity shock in region n and sector j increases the comparative advantage of all firms in region n and sector j. This affects relative prices and shifts expenditure towards output produced in region n and sector j.

To be more precise, given initial factor prices w_n and r_n, a rise in fundamental productivity in region n and sector j lowers the unit costs of intermediate goods production. As a result, input costs x_n^j and the local price index P_n^j decline. In response, the home expenditure share $\hat{\pi}_{nn}^j > 1$ in region n and sector j increases. In other words, region n gets less open than before, $\hat{\pi}_{nn}^j > 1$, and region n tends to produce a larger, but on average less productive subset of varieties in sector j. At the same time all other regions reduce their home expenditure shares $\hat{\pi}_{ii}^j < 1$, for $i \neq n$ and all k, as they now import more intermediates from sector j in region n. Now, the varieties of intermediate goods still produced in all other region-sector pairs i, j for $i \neq n$, have relatively higher idiosyncratic productivities, which increases measured TFP in those regions. This is the so-called 'selection effect'.[9]

The sector-specific trade elasticity θ^j represents the variability of technology levels across goods and regions and therefore governs the comparative advantage within sectors. The parameter θ^j scales the change in trade-relationships between regions within sectors, captured by the change in home expenditure shares $\hat{\pi}_{nn}^j$. As the trade elasticity θ^j increases (smaller dis-

[9] For further information, see Levchenko and Zhang (2016), Tombe and Zhu (2019), Eaton and Kortum (2012) and Costinot and Rodríguez-Clare (2014).

persion in idiosyncratic productivity levels within sector j), the term $[\hat{\pi}^j_{nn}]^{1/\theta^j}$ in equation (18) approaches one and changes in fundamental productivity $\hat{T}^j_n$ crowd out the 'selection effect' in determining changes in measured productivity. In other words, with higher trade elasticities θ^j the 'selection effect' gets less important.

In sum, trade linkages ensure that productivity shocks propagate across regions and sectors, which affects the selection of firms and the average productivity of the firms that survive on the market (see, e.g., Finicelli et al., 2013, Costinot et al., 2012). The denominator of the second term on the right-hand side of equation (18) exactly accounts for this trade-driven selection. As a result, the change in measured TFP, $\hat{A}^j_n$, in region n and sector j is lower than the change in fundamental productivity, $\hat{T}^j_n$.

Factor reallocation and input costs. Equations (19) and (20) demonstrate that the same factors that contribute to changes in measured TFP also affect changes in real GDP and welfare. The reallocation of labor across regions and sectors, and changes in relative factor prices, inputs costs, and receipts from the national portfolio in response to fundamental productivity changes, further influence the change in real GDP and welfare. The second term on the right-hand side of equation (19) shows that an increase in labor proportionally increases real GDP. The intuition is simple. Because of constant returns to scale in production and perfect competition, the price index decreases and nominal wages $\hat{w}_n > 1$ increase in response to productivity improvements. Rising nominal wages attract labor $\hat{L}_n > 1$ from other regions and sectors, which contributes to the growth of local real GDP and acts as an additional agglomeration force.

In each location, however, land and structures H_n are fixed in supply and local rents r_n rise proportionally with an increase of nominal wages w_n and labor L_n, $w_n L_n = [\beta_n/(1-\beta_n)]r_n H_n$. From equation (4) it gets evident that input costs x^j_n increase with rising wages and local rents (depending on the strength of input-output linkages). When input costs increase more than nominal wages, this will work against the positive selection and labor reallocation effects. Hence, the term $(\hat{w}_n/\hat{x}^j_n)$ in equations (19) and (20) shows that an increase of fundamental productivity that positively affects the growth of real GDP and welfare can be counterbalanced by a higher increase of input costs relative to nominal wages, which represents a congestion force in the model.

Regional transfers of local rents. A smaller increase of per capita receipts from the national portfolio relative to an increase of input costs works as an additional congestion force. The transfers from the national portfolio aim to capture trade imbalances between regions and influence factor reallocation (and therefore real GDP) and local welfare. The third term on the right-hand side of equation (20) shows that given fixed contribution shares ι_n, the relative value of receipts per capita from the national portfolio, $\chi = \sum_i \iota_i r_i H_i / \sum_i L_i$, mechanically decreases with an increase of input costs x^j_n in response to a local productivity shock. Regions without positive productivity developments, however, benefit from higher per capita receipts from the national portfolio without having to bear the burden of rising input cost, which works as an agglomeration force for these regions.

In equilibrium, congestion forces from rising input costs and declining relative receipts per capita from the national portfolio counterbalance the positive agglomeration force from rising nominal wages and prevent all workers from residing in the most productive place. Note that in contrast to costly trade the transfers between regions are not subject to any frictions. Income transfers between regions, therefore, play a key role in aggregate welfare. Local factor price changes affect the income of all agents in the economy via linkages from the national portfolio. This generates inefficiencies in the model as mobile workers impose externalities on the local rents received by other agents.

Summary. The previously described channels suggest that local fundamental productivity growth leads to higher measured productivity, output, and welfare. Local productivity growth attracts additional workers depending on the relative strength of local agglomeration and congestion forces. Agglomeration forces are larger for regions with stronger trade and input-output linkages. As such, central regions with strong spatial linkages in the production network can source inputs at lower costs, thus generating a competitive advantage and leading to lower trade costs. Positive local productivity growth further strengthens this competitive advantage providing an incentive of workers to agglomerate in this region. Areas that lack abundant land and structures display a large degree of initial congestion (indicated by high input costs), making it difficult to attract additional labor in response to positive local productivity growth. As such, initially less congested regions can attract a larger share of employment making it more attractive to allocate local productivity growth in initially smaller regions. An additional argument relates to net contributions towards the national portfolio. While being a net recipient may appear well for local consumption, being a net donor serves as an additional congestion force and prevents labor from migrating to the most productive (donor) regions.

In reality, all these channels work together and the aggregate implications of local productivity growth depend on the actual strength of relative agglomeration and dispersion forces for all regions. We, therefore, calibrate the model for the German economy accounting for the linkages between sectors and regions, interregional transfers and labor mobility. In a counterfactual analysis, we then analyze the impact of spatial development, measured by positive local productivity growth, on the aggregate economy.

2.3 Quantification

To be able to analyze the impact of local productivity changes, we start with the quantification of the model and briefly describe the data and discuss our parameter choice. Next, we empirically identify the central locations with the strongest spatial links in the domestic production network.

2.3.1 Data

Quantifying the model requires data on sector-specific output and input-output linkages, sector-region-specific value-added, inter-regional bilateral trade flows per sector, as well as data on employment and wage income per region and sector. Our calibration of the model is for 2010, as it is the most recent year for which all relevant information is available. In our analysis, we aggregate sectors at the 1-digit level represented by the ISIC Revision 4 classification and distinguish between $J = 7$ industries. Four tradable sectors and three non-tradable sectors.[10] The tradable sectors are Agriculture, Mining, Manufacturing and Retail trade. The non-tradable sectors include Construction and Financial Services and the Public sector including public administration. At the regional level, our unit of observation are the 402 German administrative districts (*Landkreise und kreisfreie Städte*). This geographic unit represents the third level of administrative division called the Nomenclature of Territorial Units for Statistics (NUTS-3). NUTS-3 regions are administrative districts whose average population usually ranges between 150,000 and 800,000 people.

Data for employment and wage income for every district are readily available from Eurostat (Eurostat, 2016) and the INKAR Database (NUTS-3 level, see INKAR, 2016). We normalize employment, to sum up to one. We use the information on sector-specific output and input-output linkages from the World Input-Output Tables (WIOD, see Timmer et al., 2015). We allocate sector-specific output across regions according to region-specific employment shares. Information on sector-region specific value-added comes from Eurostat.

We use information on interregional trade flows from the Forecast of Nationwide Transport Relations in Germany 2030 (Verkehrsverflechtungsprognose 2030, henceforth VVP) provided by the Clearing House of Transport Data at the Institute of Transport Research of the German

[10]Table 2.4 in Appendix 2.C presents a summary of all data sources and Table 2.5 in Appendix 2.C lists the different sectors.

Aerospace Center (see Schubert et al., 2014).[11] The data contain bilateral trade volumes in metric tons at the product level by transport mode (road, rail, water) that went through German territory in 2010. We aggregate trade flows to the $N = 402$ German administrative districts (Kreise and kreisfreie Städte) and across transport modes at the 1-digit level of the ISIC Revision 4 classification. Moreover, our theoretical model requires trade *values* rather than *volumes*, so we convert the data by using appropriate unit values. We match aggregate trade flows in metric tons to output per region and sector in millions of euro and calculate the corresponding unit values. This procedure is convenient for two reasons: First, we can derive region-sector-specific unit values based on actual output data.[12] Second, using the unit values per region-sector pair together with information on region-sector-specific trade volumes from VVP we can match region-sector-specific gross output.

2.3.2 Parameter choices

In this subsection, we discuss the choice of parameters that we hold constant across our counterfactual simulations. We choose values for $\{\alpha^j, \beta_n, \gamma_n^j, \gamma_n^{jk}, \iota_n\}$ to match observable data. We calculate the consumption share α^j as the total expenditure of sector j goods, adjusted by the intermediate goods expenditure and divided by the total final absorption. Since we use two input factors, we must identify the share of labor $(1 - \beta_n)$ in the production function. For this purpose, we divide the sum of labor income $w_n L_n$ by region n's value-added. Similarly, we compute the share of value-added in gross output γ_n^j as the ratio of value-added over gross output, VA_n^j / Y_n^j. Next, we use the γ_n^j's to determine the share of sector j goods used in sector k and region n, γ_n^{jk}. Taking national input-output shares γ^{jk}, we notice that $\gamma_n^{jk} = (1 - \gamma_n^j)\gamma^{jk}$.[13] Once we have identified the share of labor $(1 - \beta_n)$ in the production function, we can calculate local rents per capita from the internal structure of the model using data on nominal wage income. Recall that the rents from land and structures can be expressed as $r_n H_n = \beta_n VA_n$, where $VA_n = 1/(1 - \beta_n) w_n L_n$. Hence, using data on nominal wage income and the parameter β_n we can solve for the respective local rents. Hence, rents per capita are higher in cities with higher nominal wage levels, like Munich (Landeshauptstadt) or Wolfsburg (kreisfreie Stadt). Local rents per capita vary significantly across regions with $14,280$ euro in Eisenach and $41,782$ euro in Wolfsburg. To determine the fraction of rents contributed to the national portfolio we match the trade imbalances $\Gamma_n^M = \iota_n r_n H_n - (\sum_{i=1}^N \iota_i r_i H_i / \sum_i L_i) L_n$ in the model to the observed imbalances Γ_n^D in the data. We search for the respective contribution shares ι_n that minimize the sum of squared residuals $\sum_{i=1}^N (\Gamma_n^M - \Gamma_n^D)^2$ subject to the constraint $\iota_n \in [0, 1]$. The predicted imbalances perform quite well to match the observed trade imbalances (although not perfectly). Moreover, regions with a trade surplus are net contributors to the national portfolio, while regions with trade deficits are net recipients (see Figure 2.6 in Appendix 2.C).

The trade elasticity θ^j plays a crucial role in the impact of trade costs. We borrow elasticities from Caliendo et al. (2018) and map their values into our sectors. Table 2.6 in Appendix 2.C displays the respective values. In the last step, we calculate a baseline counterfactual economy and remove any remaining unexplained differences between trade imbalances in the model and the data. With this procedure, differences between Γ_n^M and Γ_n^D, which the estimation procedure of ι_n was not able to account for, vanish. The new equilibrium serves as our starting point from which all other counterfactual simulations are conducted. To achieve this perfect fit of the model to the data, we allow for adjustments in trade costs κ_{ni}^j and productivity T_n^j levels. This procedure has the advantage that we do not need to alter any official statistical data but only ex-ante unobservable variables. We consider this procedure an appropriate alternative to

[11] The data can downloaded from http://daten.clearingstelle-verkehr.de/276/. It is similar to the US commodity flow survey.

[12] The derived unit values highly correlate with alternative unit values calculated using the ratio of values and quantities based on trade data from COMTRADE.

[13] To see this, recall that $\sum_k \gamma_n^{jk} = 1 - \gamma_n^j$ and that on the national level $\sum_k \gamma^{jk} = 1$.

Caliendo et al. (2018) who change the distribution of economic activity across space to calculate a baseline counterfactual economy, as they let observed wages w_n and labor shares L_n adjust endogenously.[14]

2.3.3 Centrality of regions and sectors

We follow the literature on network analysis and define regions as central, when all its trading partners have high import shares from that region and when neighboring regions in the network are themselves well connected. To be more precise, to highlight the importance of the strength of spatial links in the economy, we transfer the concept of 'eigenvector centrality' to the German trade network in 2010 and follow Carvalho (2014) to calculate the Katz-Bonacich eigenvalue centrality measure. The 'centrality' measure captures the argument that more centrally located regions have the comparative advantage in producing and exporting goods to surrounding regions, and therefore stronger spatial links. According to our model, more central regions either have higher productivity levels T_n^j, lower trade costs κ_{in}^j, or a higher share of value-added in gross output γ_n^j (see equation (8) on the expenditure share π_{in}^j, that translates into the centrality measure). To calculate the centrality measure for each region $n \in N$, $c_n > 0$, we add to some baseline centrality level across all regions, $\eta = 0.5/N$, the weighted sum of the centrality weights of each regions trading partners, where we use the import shares, $\pi_{in} = \sum_j \pi_{in}^j$ for all region pairs i, n as weights: $c_n = \lambda \sum_i \pi_{in} c_i + \eta$, with $\lambda = 0.5$.[15] The vector of centralities is given by $c = \eta(I - \lambda\Pi)^{-1}\mathbf{1}$, where Π, is the import share matrix, and $\mathbf{1}$ is a vector of ones.

We find that regions differ significantly with respect to their network centrality.[16] The most central regions are big and productive cities, like Munich (Landeshauptstadt), Berlin and Hamburg, with respective centrality measures of 0.680, 0.631 and 0.517 (in hundreds). Regions like Bremerhaven (kreisfreie Stadt, 0.181) and Emden (kreisfreie Stadt, 0.183) (in hundreds) feature the lowest centrality measures. Table 2.1 explores how the 'centrality measure' relates to other economic characteristic on the regional level. It shows that, for example, more central regions in the trade network are more employment-intensive, more engaged in the manufacturing sector, and more important for the overall production process as measured by their value-added and gross output shares.

To determine the relative importance of sectors in the aggregate economy, we also calculate centrality measures for each sector based on the national input-output shares γ^{jk}. The Financial 24.68, Wholesale 18.84, and Manufacturing sector 17.03 (in hundreds) are the most central sectors in the network, while Agriculture 7.96, Mining/Quarrying, Electricity, Gas, Water Supply 11.10, Construction 10.09, and Public Administration, Defense, Social Security, Human Health 10.30 are less central on the aggregate level. Note, however, that the relative importance of the different sectors varies across regions as represented by the region-specific expenditure shares for materials from other sectors γ_n^{jk} in our model.

As some regions and sectors are more central than others in terms of their relative connectivity within the domestic production network, we would expect that they are also relatively more important in transmitting local productivity growth and determining aggregate economic activity. Hence, in our analysis, we will refer to the concept of centrality as one important

[14] Our procedure leaves us with minor changes for trade costs between −1.81 percent and +1.93 percent, while changes in productivity are more pronounced. For the model imbalances to match the data, we need sizeable changes in productivity. For example, Potsdam (kreisfreie Stadt)'s productivity must increase by 9.80 percent while Altenburger Land's productivity must decline by 9.37 percent.

[15] The literature on network analysis documents several concepts to measure the connectedness and relative importance of different nodes within networks. See, for example, Carvalho (2014), Bonacich (1972) and Ballester et al. (2006). Moreover, Carvalho (2014) gives a nice survey and describes different measures in the context of production networks with input-output linkages. For our purpose the concept of 'eigenvector centrality' is the most suitable measure, as it allows us to analyze the existing domestic trade network in Germany.

[16] See Figure 2.7 in Appendix 2.E. The qualitative results are robust to the choice of η and λ. Both measures are the same for all regions and thus do not change their ordering.

statistic in determining the propagation of local productivity shocks.

Table 2.1: Centrality Distribution with Other Variables in 2010

	Quartiles of Centrality			
	1	2	3	4
Share of Total (in percent)				
Employment	0.10	0.16	0.23	0.51
Manufacturing	0.21	0.23	0.25	0.26
Value-added	0.09	0.14	0.22	0.55
Gross output	0.11	0.16	0.23	0.50

Notes: We split regions into quartiles of the centrality measure. For each quartile, we then calculate the average across sectors and regions for the respective characteristics. We calculate these numbers for the year 2010.

2.4 The impact of local productivity changes

In this section, we use the model from Section 2.2 to analyze the impact of local productivity changes in Germany. The section is composed of two parts. First, we identify the places — so-called key regions — with the highest potential to affect the German economy in terms of aggregate TFP, real GDP, and welfare. Second, we examine the impact of observed local productivity changes and evaluate the economic performance of those key regions between 2010 and 2015.

2.4.1 Identifying key regions

The goal of this subsection is to identify the key regions for the aggregate economy. To do so, we consider a productivity shock of 10 percent, $\hat{T}_n^j = 1.10$, for all sectors j within a given region n and solve for the new equilibrium. We repeat this exercise for all $n \in N$ regions and calculate the aggregate changes in TFP, output, and welfare.

To calculate changes in measured TFP on either the region, sector, or aggregate level, we use gross output shares. Respective changes in measured TFP on the national level, for example, are simply weighted averages of disaggregated changes in measured TFP for each region-sector pair (n, j):

$$\widehat{A} = \sum_{j=1}^{J} \sum_{n=1}^{N} \frac{Y_n^j}{\sum_{j=1}^{J} \sum_{n=1}^{N} Y_n^j} \hat{A}_n^j, \tag{21}$$

where $Y_n^j = w_n L_n^j / \gamma_n^j (1 - \beta_n)$ is equilibrium gross output (see Appendix 2.D for details).

Real GDP is a value-added measure so we use value-added shares as weights. Hence, aggregate change in real GDP is given by:

$$\widehat{\text{GDP}} = \sum_{j=1}^{J} \sum_{n=1}^{N} \frac{w_n L_n^j + r_n H_n}{\sum_{j=1}^{J} \sum_{n=1}^{N} (w_n L_n^j + r_n H_n)} \widehat{\text{GDP}}_n^j. \tag{22}$$

The literature on the macroeconomic consequences of microeconomic shocks has identified so-called "Domar weights" in a perfectly competitive economy as a sufficient statistic to understand the first-order impact of local shocks on the aggregate economy (see, e.g., Domar, 1961 and Hulten, 1978). In other words, for efficient economies, the sales share or Domar weight Y_n/Y

is a sufficient statistic to evaluate the first-order effects of disaggregated productivity shocks to aggregate welfare and real GDP. In this sense, to a first-order, the input-output and trade linkages, as well as the reallocation of labor across sectors and regions are not relevant for the impact of disaggregated productivity shocks on the aggregate economy (see Baqaee and Farhi, 2019). To account for the heterogeneity in the initial economic importance of different regions and sectors, we calculate aggregate elasticities and normalize the aggregate TFP change by each region's output share, the aggregate real GDP change by each region's wage income share w_nL_n/wL and the change in welfare by the labor share L_n/L. This ensures that the aggregate elasticities do not vary systematically with the respective shares. We will see that the input-output and trade linkages, as well as the reallocation of labor across sectors, play dominant roles for the respective results.[17] To make the identical shock comparable across the different regions we multiply all values by the size of the fundamental productivity shock.[18] The aggregate elasticities are given by:

$$\mathrm{TFP}^{\mathrm{elas.}} = \frac{dA}{dT_n}\left(\frac{Y_n}{Y}\right)^{-1}; \ \mathrm{GDP}^{\mathrm{elas.}} = \frac{dGDP}{dT_n}\left(\frac{w_nL_n}{wL}\right)^{-1}; \ \mathrm{Welfare}^{\mathrm{elas.}} = \frac{dU}{dT_n}\left(\frac{L_n}{L}\right)^{-1}. \quad (23)$$

We find that locations differ significantly in terms of their aggregate elasticities. Figure 2.1 presents the geographic distribution of the aggregate elasticities.[19] In general, regions in the western and southern parts of Germany exhibit the highest aggregate elasticities. Surprisingly, for aggregate output and welfare we do not identify the biggest and most productive cities, but smaller regions in their surroundings as key for the aggregate economy. Hence, regions that are geographically close and well connected to highly productive cities have on average a larger impact on the aggregate economy. The intuition is that these less congested regions can attract a larger share of workers in response to positive productivity shocks. They can grow and reap the benefits of rising nominal wages without increasing local rents and input costs, which is the congestion force in the model, too much. This suggests that the big cities like Munich, Berlin, and Hamburg are already relatively congested and cannot attract additional employment without rising local rents significantly.

Figure 2.2 also documents that regions with higher elasticities are on average more central in the domestic production network. This means that local productivity shocks in central regions spill over to many other locations. However, the biggest and most central regions only have an average aggregate elasticity. Furthermore, we find that key regions in terms of aggregate welfare are net contributors to the national portfolio. They contribute more to the national portfolio than they receive on average. Hence, these regions attract a large share of labor in response to positive productivity shocks, while in the meantime redistributing a larger share of their higher income to the rest of the economy.

Summary. To sum up, regions differ concerning their aggregate TFP, real GDP and welfare elasticities. Depending on the specific aggregate measures of TFP, output, or welfare, we identify different regions as the main important players for the aggregate economy. In the case of Germany, concentrating local productivity growth in the biggest and most productive cities does not maximize aggregate output and welfare. Spatial development policies that affect local productivity growth exhibit larger aggregate effects in smaller regions in the surroundings of big cities. The key regions in spatial development have relatively strong spatial linkages and are less

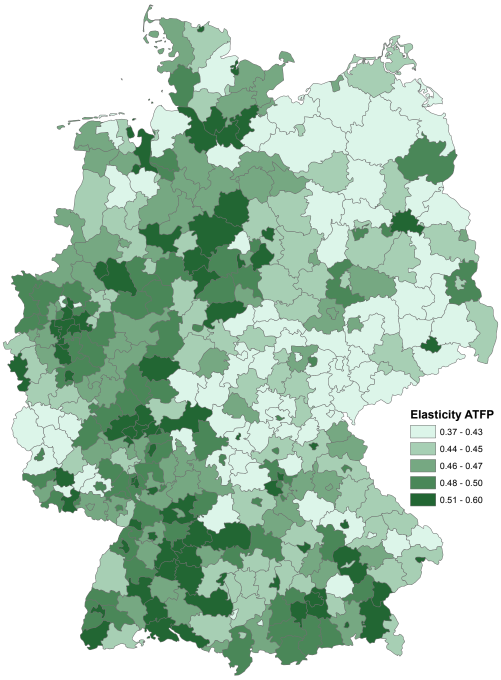
[17] We restrict our analysis to identify the key regions, because of the relatively high level of sectoral aggregation in our data.

[18] The actual shock size is only of minor interest. We conduct various robustness checks and vary the shock size with smaller values of $\{2, 4, 6\}$ percent as well as negative values $\{-10\}$ percent. The qualitative implications do not change. For the negative productivity change, the rank correlation compared to the positive counterpart varies between 0.88 (welfare) and 0.99 (TFP).

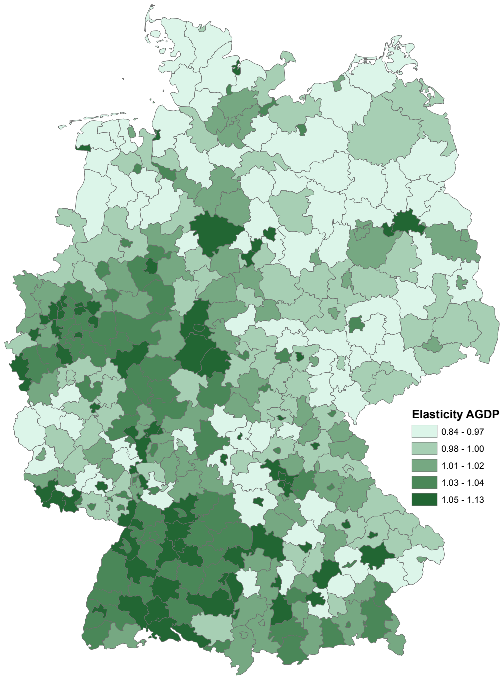
[19] Table 2.7 in Appendix 2.E provides a list of the 15 top and bottom regions concerning the aggregate elasticities.

Figure 2.1: Aggregate Elasticities, by Region

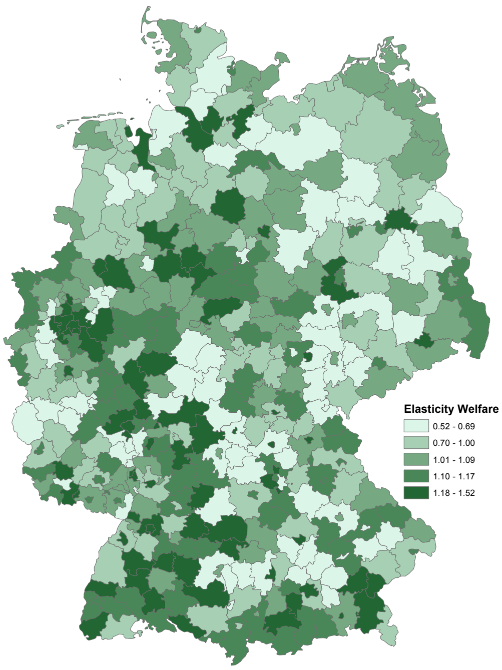
(a) Aggregate TFP Elasticities



(b) Aggregate GDP Elasticities



(c) Aggregate Welfare Elasticities

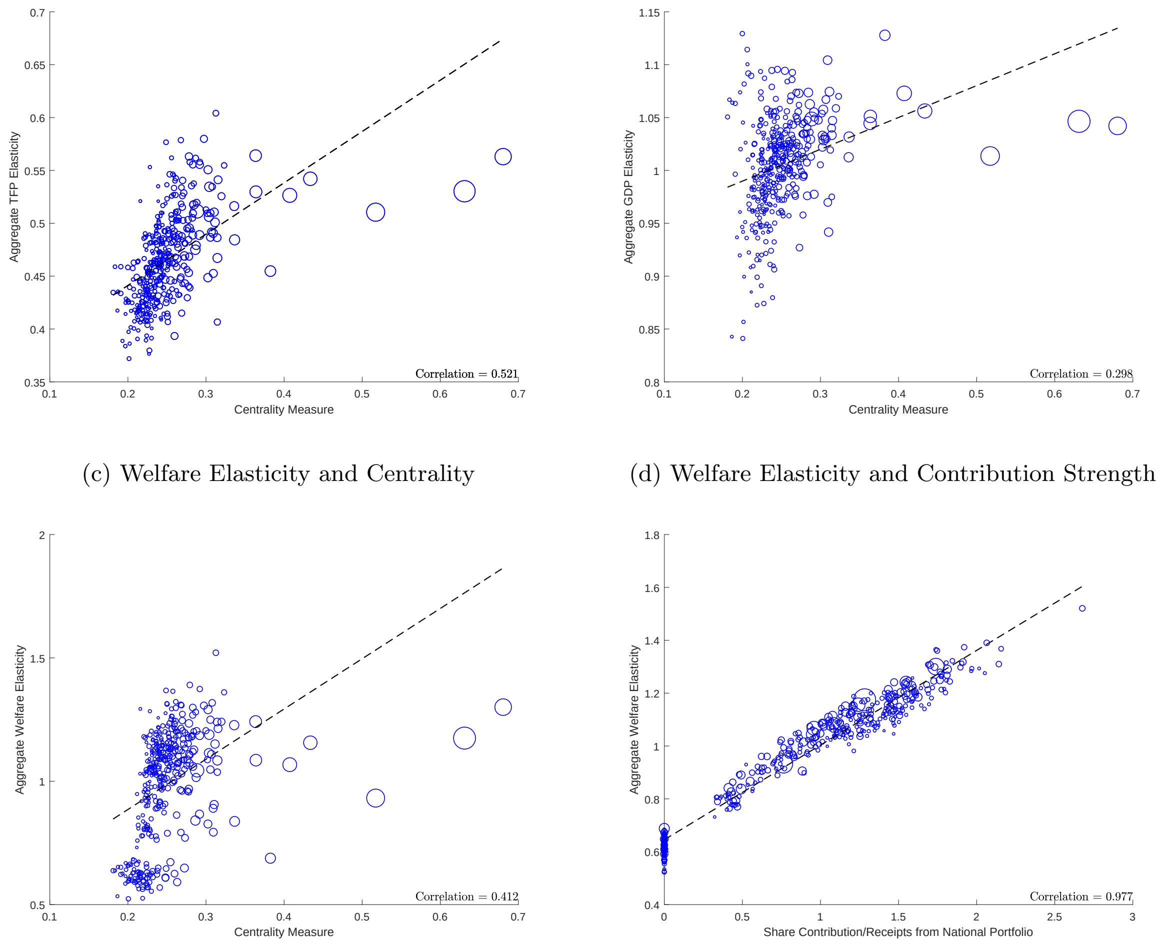


Notes: This figure plots the aggregate TFP, real GDP, and welfare elasticities of a 10 percent fundamental productivity shock to all sectors in a given region. Darker shading indicates higher values.

congested to attract a larger share of workers in response to positive productivity growth.[20]

[20]In Appendix 2.F, we decompose the aggregate effect into a direct effect and a spillover effect. We show that

Figure 2.2: Influencing Factors for Aggregate Elasticities



(a) TFP Elasticity and Centrality

(b) GDP Elasticity and Centrality

(c) Welfare Elasticity and Centrality

(d) Welfare Elasticity and Contribution Strength

Notes: Panel (a) plots the relationship between the centrality measure and aggregate TFP elasticities. The size of the marker is proportional to the initial output share of each region. Panel (b) shows the relationship between the centrality measure and aggregate GDP elasticities. The size of the marker is proportional to the initial value-added share of each region. Panel (c) displays the relationship between the centrality measure and aggregate welfare elasticities. Panel (d) plots the strength of contributions to the national portfolio (i.e., the ratio of contributions to receipts from the national portfolio) against the aggregate welfare elasticity. In both cases, the size of the marker is proportional to the initial employment share of each region.

2.4.2 Evaluating changes in local productivity

To identify local productivity changes per region and sector, we employ standard growth accounting techniques. We use the model structure and regional data on wages, employment, and prices to calculate the local productivity change $\hat{T}_n^j$ between 2010 and 2015. We assume a constant production structure, perfect competition under constant returns to scale, market clearing, and cost minimization. Intuitively, we measure the growth of real output relative to changes in input factors and costs. We proceed in three steps: i) using the structure of the model we organize official statistical data in an internally consistent way to recover the changes in input costs, ii) using the changes in input costs together with observed changes in real output, employment and wages we calculate the measured TFP model counterpart, and iii) using the

spillover effects in all other regions not directly affected by productivity changes are highly important to explain the aggregate results.

changes in measured TFP we calculate the model-based changes in fundamental productivity. As data on actual changes of TFP and detailed changes in input costs are not readily available, we manipulate equation (19) to calculate the measured TFP model counterpart using observed data on real output, employment, and wages:

$$\ln(\hat{A}_n^j) = \ln(\widehat{\text{GDP}}_n^j) - \ln(\hat{L}_n^j) - \ln(\hat{w}_n^j/\hat{x}_n^j). \tag{24}$$

We normalize the data to have a mean of one. From a theoretical point of view, a change in measured TFP depends on several factors. First, a change in real output leads, everything else equal, to a one-by-one change in measured productivity. Second, when output increases at a lower rate than employment, the net effect on productivity is negative. Third, when wages increase at a higher rate than input costs, this too lowers measured productivity. We calculate the region-sector specific wage changes $\hat{w}_n^j$ as a composite measure consisting of the change in nominal wages $\hat{w}_n$ per region, and sector-specific wage changes $\hat{w}^j$ from official statistical data. As we lack data on detailed changes in input costs, we solve for the corresponding changes using data on changes in prices, employment, and wages between 2010 and 2015. To compute $\hat{x}_n^j$, we use the information on changes in employment, wages and the relevant parameters on the share of value-added in gross output, γ_n^j and γ_n^{jk}, and the wage share in the production of value-added, β_n. We quantify the change in input costs according to:

$$\ln(\hat{x}_n^j) = \gamma_n^j \left[\ln(\hat{w}_n) + \beta_n \ln(\hat{L}_n)\right] + \ln\left[\prod_{k=1}^{J} (\hat{P}_n^j)^{\gamma_n^{jk}}\right]. \tag{25}$$

To proxy the changes in input costs, we need information on price changes $\hat{P}_n^j$, for which — to the best of our knowledge — no region-sector specific official statistical data are available. Therefore, we use an iterative algorithm over the changes, which minimizes the squared deviation of the weighted sum of region-sector TFP across both regions and sectors from the aggregate change in measured TFP, where the weights are equal to the value of gross output shares. As starting values for the changes in region-sector specific intermediate goods prices, $\hat{P}_n^j$, we calculate the product of sector-specific price changes from WIOD and region-specific price changes from Eurostat. This procedure matches the sector-specific increases of measured multifactor productivity in Germany between 2010 and 2015 from the EU KLEMS Productivity and Growth Accounts (see Ark and Jäger, 2017).[21] As a result, we get the change in measured TFP per region-sector pair defined as $\hat{A}_n^j = A_n^{j,2015}/A_n^{j,2010}$, where the gross output share weighted sum over regions n and sectors j exactly matches the aggregate change in measured productivity.[22] In the next step, we use equation (18) to calculate the model-based changes in fundamental productivity, $\hat{T}_n^j$, in region n and sector j using the changes in measured TFP:

$$\hat{T}_n^j = \hat{A}_n^{j\,1/\gamma_n^j}, \tag{26}$$

where we abstract from trade and selection effects, i.e., any changes in the home intermediate expenditure shares, $\hat{\pi}_{nn}^j$.[23] Further, to analyze whether a region or sector experiences a rise or decline in TFP between 2010 and 2015, we either aggregate the corresponding region-sector specific measurements to the regional, $\hat{T}_n$, or sectoral, $\hat{T}^j$, level using regional or sectoral GDP shares as weights.

[21] The data can be downloaded from http://www.euklems.net/.

[22] In Appendix 2.G we describe the specific procedure in more detail.

[23] To account for extreme values that arise in the case of small value-added shares, we winsorize the respective values at the 10 percent and 90 percent percentiles.

Table 2.2 displays the productivity changes per sector. The Manufacturing and Wholesale, as well as the non-tradable sectors Construction and Financial/Insurance Activities, developed positively concerning fundamental TFP between 2010 and 2015. The growth factors range between 1.076 and 1.157. The sectors with fundamental productivity losses are Agriculture and the Public sector, for which we observe growth factors of 0.707 and 0.925, respectively. While there are no empirical counterparts for our calculated fundamental productivity changes, we can compare the underlying changes in measured TFP $\hat{A}^{j,model}$ to their empirical equivalent $\hat{A}^{j,data}$ coming from the EU KLEMS Productivity and Growth Accounts. According to columns (3) and (4) of Table 2.2, the model-induced growth factors in measured TFP match closely to the data for all sectors, except for Mining/Quarrying (1.125 versus 1.020) and Construction (1.120 versus 1.035). These differences can be justified threefold. First, our model includes an imperfect measure for capital by including the input factor *land and structures*. Second, we could only approximate the changes in input costs, $\hat{P}_n^j$. In particular, for the Construction sector, there has been a substantial increase in the input prices $\hat{P}_n^j$ in recent years, which are not fully captured by our routine. Finally, there are also slight methodological differences in quantifying total factor productivity.[24] Overall, we are, however, confident to provide reasonable numbers for disaggregated changes in fundamental TFP, as we correctly predict the sign of all changes in measured TFP.

Table 2.2: Sectoral Productivity Changes, 2010−2015

Sector (Tradable, Non-tradable)	**Model**		**Data**
	$\hat{T}^j$	$\hat{A}^j$	$\hat{A}^j$
Agriculture, Forestry, Fishing	0.707	0.784	0.780
Mining/Quarrying, Electricity, Gas, Water Supply	1.159	1.125	1.020
Manufacturing	1.076	1.062	1.060
Wholesale	1.131	1.104	1.120
Construction	1.157	1.120	1.035
Financial and Insurance Activities	1.057	1.045	1.030
Public Administration, Defense, Social Security, Health	0.925	0.978	0.999

Notes: This table displays the per-sector growth factors (values > 1 indicate positive growth) of fundamental productivity changes $\hat{T}^j$ (model) and measured TFP changes $\hat{A}^j$ (model and data) from 2010 to 2015. The data comes from the EU KLEMS Productivity and Growth Accounts.

Figure 2.3 displays the geographical distribution of fundamental productivity changes $\hat{T}_n$. Regions in the northeast of Germany exhibit larger values indicating a catch-up process between 2010 and 2015. Note, however, that this catch-up process is not only due to a positive real GDP growth, but also comes from employment losses in the northeast of Germany between 2010 and 2015.[25]

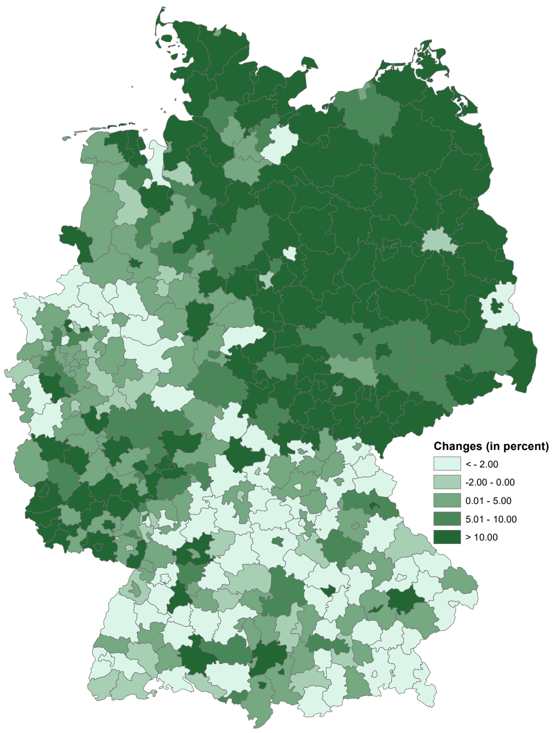
To further pin down the realized patterns, we estimate the elasticities of local productivity changes concerning the employment shares and the centrality of regions in 2010 from a simple 'Ordinary Least Squares' (OLS) regression. Panel (a) and Panel (b) of Figure 2.4 indicate a smaller productivity increase in already agglomerated and centrally located areas showing a negative relationship between initial employment shares as well as the centrality measure and local productivity changes. In other words, although we observe a concentration of labor in the largest cities and most central locations, the increase of local productivity was less pronounced in these areas between 2010 and 2015. In the following analysis, we will quantify the implied

[24]For example, there are different measures for TFP. Based on value-added per hour worked or value-added per person employed. Ademmer et al. (2017) provide a more detailed overview of this topic.

[25]Figure 2.11 in Appendix 2.G displays the changes in fundamental productivity for the Agriculture and Manufacturing sector per region. The plots for the remaining sectors are available upon request.

aggregate effects of these patterns of local productivity changes using the structure of the model.

Figure 2.3: Geographical Distribution of Local Productivity Changes, 2010−2015



Notes: This figure plots the geographical distribution of fundamental productivity changes, $\hat{T}_n$ (in percent). A darker shading indicates higher values.

After having identified the key regions and their observed changes in local productivity, we aim to evaluate their actual performance. To quantify the impact of local productivity changes on the development of the German economy between 2010 and 2015, we simulate a baseline scenario (accounting for all observed local productivity changes) and compare the outcome to various counterfactual scenarios where we abstract from local productivity changes in a given region (or group of regions). For the relevant location, we set $\hat{T}_n^j = 1$ for all sectors, while accounting for the productivity changes of all other regions. This allows us to quantify the marginal (or cumulative) effect of observed local productivity changes on aggregate TFP, real GDP, and welfare. Whenever abstracting from observed local productivity changes leads to declines in the outcome variables (relative to the baseline scenario), we infer that the region positively contributed to the development of the aggregate economy between 2010 and 2015.[26] If, on the other hand, abstracting from local productivity changes does not substantially change the outcome variables, or worse, rises aggregate TFP, real GDP or welfare, we conclude that a region has not developed according to its potential. A rise in either of the outcome variables even means that without the observed local productivity changes, the aggregate economy would have performed better. However, this is only possible if the region's actual contribution to the aggregate change was negative. In our counterfactual analysis where we account for all observed local productivity changes, the aggregate implications are not clear ex-ante. When productivity in hundreds of cities and regions changes simultaneously, some places will attract economic activity at the expense of others. Even when local productivity increases significantly

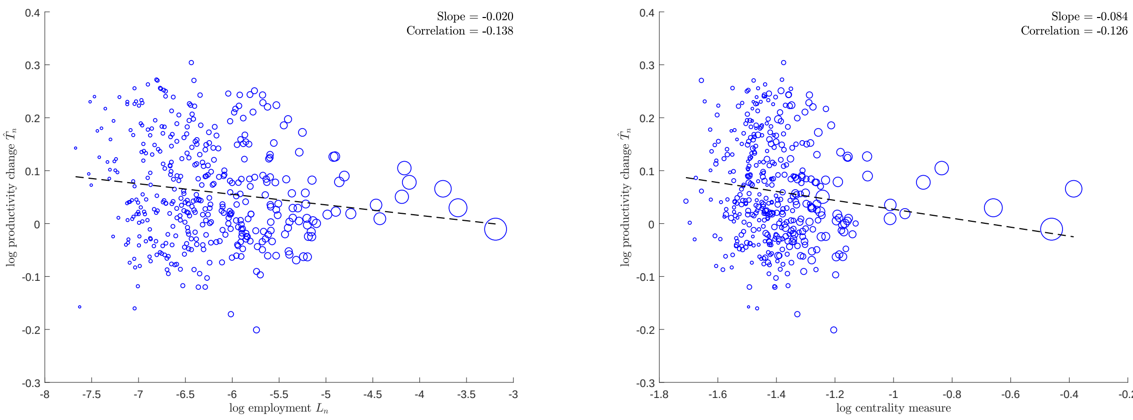
[26]Note, that this exercise does not allow us to evaluate whether key regions developed according to their potential in absolute terms. All we can determine is if locations with the highest potential contributed more to the aggregate than locations with a lower potential.

for a single region, it may be harmful to the economy as a whole, as it diverts economic activity away from key regions with a higher aggregate elasticity.

Figure 2.4: Local Productivity Changes, 2010−2015

(a) Did larger regions get more productive?

(b) Did central regions get more productive?



Notes: Panel (a) plots the relationship between initial employment shares and local productivity changes. Panel (b) the relationship between the centrality measure and local productivity changes. The size of the marker is proportional to the regional employment growth between 2010 and 2015.

In the baseline scenario, aggregate TFP increases by 4.15 percent, aggregate real GDP by 9.81 percent, and the gain in welfare amounts to 5.92 percent. As a welcome side effect, the resulting changes fit quite well to observed aggregate changes for the German economy as published by the OECD, where Germany experienced an increase of multifactor productivity by 4.39 percent (which implies a compound annual growth rate of $1.0439^{1/5} = 1.0086$, that is 0.86 percent per year), and an increase of real GDP by 8.90 percent (i.e., 1.72 percent per year) from 2010 to 2015.[27] In the following exercise, we normalize the baseline scenario to zero and report relative deviations from this baseline case in percentage points.

Figure 2.5 displays the results for aggregate TFP, real GDP, and welfare. Abstracting from the observed productivity changes step-by-step from the upper end to the lower end of the aggregate elasticity distribution affects the aggregate measures with varying impact. When we suppress the productivity changes for all regions between 2010 and 2015, we trivially lose the entire gains of the benchmark scenario. The left y-axis depicts the cumulative effect of jointly abstracting from productivity changes for a group of regions $\{1, \ldots, i\}$ ranked by their respective elasticity distribution. For example, if we evaluate the top 10 regions with the highest values in the respective aggregate elasticity distribution — displayed by the value on the x-axis — we abstract from the observed productivity changes in all sectors of this subset of regions while accounting for the observed productivity changes of the remaining $N - 10$ regions. Similarly, on the right y-axis, we display the marginal effect of observed productivity changes. Here, we abstract from the observed productivity changes of one single region, while accounting for all the other $N - 1$ observed productivity changes.

TFP. According to Panel (a) in Figure 2.5, the key regions in terms of aggregate TFP indeed experienced productivity gains and contributed significantly to the increase of aggregate TFP between 2010 and 2015. The top 10 percent of locations account for 18 percent of the entire aggregate productivity gains, calculated as the respective 0.75 percentage points reduction relative to the overall effect of 4.15 percentage points (left axis). This corresponds to abstract-

[27] The data can be downloaded from `https://data.oecd.org/lprdty/multifactor-productivity.htm`.

ing from the productivity gains associated with the top 40 key regions, among them are cities like Ludwigshafen am Rhein (kreisfreie Stadt), Wiesbaden (kreisfreie Stadt), Leverkusen (kreisfreie Stadt), but also Munich (Landeshauptstadt). These key regions also have relatively high marginal effects concerning aggregate TFP (right axis). Specifically, when we abstract from the productivity changes of Munich (Landeshauptstadt) aggregate TFP drops by 0.14 percentage points, for Frankfurt am Main (kreisfreie Stadt) by 0.13 percentage points and for Wiesbaden (Landeshauptstadt) by 0.05 percentage points, relative to the benchmark scenario. For some regions we find positive marginal effects indicating actual negative local productivity growth. Examples are Göttingen (Landkreis, 0.01 percentage points) and Rhein-Neckar-Kreis (Landkreis, 0.02 percentage points).

Real GDP. Panel (b) of Figure 2.5 displays the effects on aggregate output. We observe only minor changes in aggregate real GDP relative to the baseline scenario when we abstract from the observed productivity changes of the key regions with the highest aggregate GDP elasticities. The cumulative effect for the first 40 regions, i.e., the top percentile of locations in the aggregate real GDP elasticity distribution, accounts for 14.68 percent of the overall effect. For the group of top five key regions, the increment is, however, rather small and sometimes positive. This corresponds to minor or even negative productivity changes for Salzgitter (kreisfreie Stadt), Landshut (Landkreis) and Aschaffenburg (Landkreis). Only when we abstract from the observed local productivity changes of central locations, like Ingolstadt (kreisfreie Stadt), and big cities like Frankfurt am Main (kreisfreie Stadt), Berlin and Hamburg, the cumulative effect gets larger culminating in a real GDP drop by 9.81 percentage points when we abstract from all observed productivity changes (left axis).

We find the highest marginal effects for the biggest cities Berlin and Munich (Landeshauptstadt), whose development — if neutralized — would lower aggregate real GDP by 0.36 percentage points and 0.34 percentage points, respectively. For the five key regions, however, the marginal effects are significantly lower, and at most 0.07 percentage points. Hence, the biggest contribution to the change in national output between 2010 and 2015 does not come from the key regions at the upper end of the aggregate real GDP elasticity distribution, indicating that the German economy remained under its potential between 2010 and 2015.

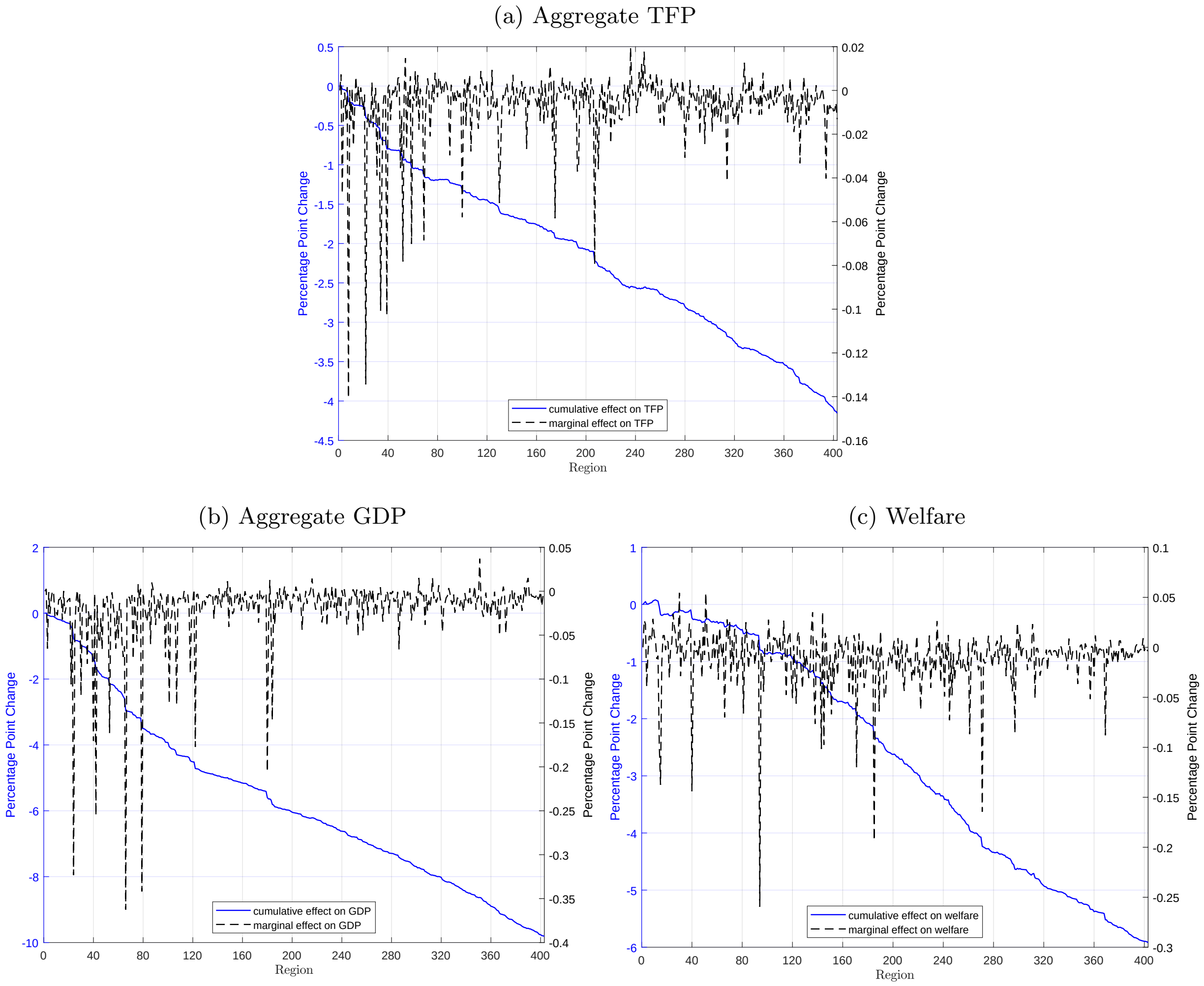
Welfare. The results for aggregate welfare are quite similar. Panel (c) of Figure 2.5 shows that locations with the highest welfare elasticities experienced declines in fundamental productivity between 2010 and 2015. The cumulative effect of abstracting from the productivity changes of the top percentile of locations in the aggregate welfare elasticity distribution translates into a welfare drop of only 4 percent. More interestingly, for the top 10 regions, we do not find an effect when we abstract from their observed productivity changes. Only when we abstract from the observed positive productivity changes of the large cities, like Munich (Landeshauptstadt), Stuttgart (Stadtkreis) and Frankfurt am Main (kreisfreie Stadt), the cumulative effect turns negative.

We find the largest marginal effects for the cities Frankfurt am Main (kreisfreie Stadt, 0.26 percentage points) and Cologne (0.19 percentage points). On the other hand, according to the model welfare would have increased by up to 0.06 percentage points if Göttingen would not have developed as quantified. In line with the findings for real GDP, the biggest contribution to the change in welfare between 2010 and 2015 comes from the productivity improvements of regions with intermediate aggregate welfare elasticities. This points to the rather poor performance of the German economy in terms of social welfare between 2010 and 2015.

2.4.3 Optimal development of the economy

Given the observed local productivity changes, we examine how far the German economy remained below its potential optimum by assuming that the key regions experienced the highest

Figure 2.5: Marginal and Cumulative Impact of Local Productivity Changes



Notes: This figure plots the impact of local productivity changes between 2010 and 2015. The baseline accounts for the complete set of productivity changes and is normalized to zero. The horizontal axis depicts the respective regions (across all sectors) ranked according to their respective aggregate elasticities. Panel (a) shows the implications for aggregate TFP, Panel (b) for real GDP, and Panel (c) for welfare. The marginal effects of abstracting from productivity changes of single regions are depicted as a dashed (black) line. The cumulative effect of abstracting from productivity changes of a group of regions is shown as the solid (blue) line. The baseline scenario, where we account for all local productivity changes between 2010 and 2015, is normalized to zero.

productivity gains. The counterfactual exercise is as follows. We assign the observed local productivity changes between 2010 and 2015 according to the previously determined ranking of aggregate elasticities. This means we attribute the largest improvements in fundamental productivity $\hat{T}_n$ between 2010 and 2015 to the key region in the respective TFP, real GDP, or welfare elasticity distribution. Within each sector, the top key region is assigned the highest productivity change and the region with the lowest elasticity the lowest productivity change. This counterfactual allows us to define the potential optimum of the aggregate economy, given the calculated local productivity changes between 2010 and 2015.

What would have happened if the key regions had developed according to the highest local productivity changes? Table 2.3 shows a large difference between the potential optimum and our baseline results. We find that aggregate TFP, real GDP, and welfare changes would be around twofold of the development in our baseline scenario. This indicates an undesirable development of local productivity changes in Germany between 2010 and 2015. We also find that the highest potential can be attributed to the key locations in terms of aggregate TFP. In other words, had key TFP regions also experienced the highest observed productivity gains, aggregate TFP would have increased by 9.43 percent (i.e., an annual compound growth rate of 1.82 percent), output by 19.21 percent (i.e., around 3.58 percent per year), and welfare by 18.13 percent (i.e., around 3.39 percent per year) within the five-year interval.

Table 2.3: Aggregate Effect of Local Productivity Changes

	Aggregate Change (in percent)		
	TFP	Real GDP	Welfare
Baseline	4.15	9.81	5.92
Assigning local productivity changes according to aggregate			
TFP elasticity	9.43	19.21	18.13
Real GDP elasticity	8.80	18.39	15.24
Welfare elasticity	7.06	15.02	14.79

Notes: This table displays the impact of local productivity changes between 2010 and 2015 on aggregate TFP, real GDP, and welfare (in percent). Row (1) displays the results for the baseline scenario in which each region and sector is assigned its actual productivity change. Rows (3) to (5) show cases in which the respective key regions of the TFP, real GDP, and welfare elasticity distributions are assigned the highest observed fundamental productivity changes.

Summary. Key regions in terms of aggregate TFP constitute the set of regions that experienced the largest increase in productivity between 2010 and 2015. However, regions with the highest potential to increase aggregate output and welfare experienced only modest fundamental productivity growth on average. We interpret this as a sign of a (relatively) poor performance of the German economy compared to its potential optimum, in terms of both real GDP and welfare. The relatively low local productivity changes in key regions lowered German output and welfare growth by a factor of two from 2010 to 2015.[28]

2.5 Conclusion

In this paper, we analyze the optimal regional allocation of spatial development policies if the government wants to maximize aggregate productivity, output, and welfare. We calibrate a general equilibrium model using disaggregated German data on input-output linkages and interregional trade to capture the complex links between sectors and regions while accounting

[28] We repeat our exercise for the set of German NUTS-2 regions to infer the importance of the geographical unit for our results. In general, we find similar qualitative patterns. The aggregate elasticities and the importance of the influence factors are similar to the NUTS-3 case. The results are available upon request. For aggregate TFP the five key regions constitute one-third of the aggregate effect. Similarly, for aggregate GDP we find that the key regions indeed experienced productivity gains. The largest contribution to aggregate real GDP comes from regions in the middle of the aggregate elasticity distribution. For welfare, the findings on the NUTS-2 regions are even more pronounced. The results show that key regions in terms of welfare experienced big losses. The findings, however, differ concerning the effect size. For GDP we estimate an aggregate change of 6.03 percentage points between 2010 and 2015 (9.81 percentage points for NUTS-3), 1.26 percentage points for TFP (4.15 percentage points for NUTS-3) and 1.55 percentage points for welfare (5.92 percentage points for NUTS-3). Hence, the granularity of the regional dimension and with it the degree of factor reallocation across regions matters for the quantitative results. The difference can be explained by taking averages when aggregating to the NUTS-2 level and by a smaller degree of labor mobility across regions. So our analysis shows that the patterns are similar but it is essential to analyze the spillover effects on a rather disaggregated level.

for the endogenous reallocation of labor and adjustment of prices in response to local productivity growth.

Our main finding is that given the current structure of the German production network local productivity growth in the most productive regions, like Munich and Hamburg, does not maximize the outcome of the aggregate economy as they are already too congested. Whether conducting spatial development policies in less productive regions gives higher aggregate growth rates than in the most productive cities depends on the strength of spatial links and the degree of congestion. In the case of Germany, less productive, central regions with strong spatial links that are not too congested are key in spatial development. Moreover, we find that depending on the primary policy goal of either increasing aggregate productivity, output, or welfare, the government should target a different set of regions.

Further, we explore whether the key regions, i.e., those locations with the highest potential to affect the aggregate economy, have also contributed the most to the development of the aggregate economy in recent years. Our calculations of the observed local productivity changes in Germany between 2010 and 2015 indicate a (relatively) poor performance of the German economy compared to its potential optimum, in terms of both output and welfare. While highly productive cities, like Berlin and Munich (Frankfurt am Main and Cologne), attracted the largest share of employment and had a major impact on aggregate output (welfare) growth, the initially less congested key regions with strong spatial linkages contributed significantly less due to relatively low productivity growth there. The relatively low economic performance of the key regions in Germany and the rising concentration of employment in the already congested cities had sizeable implications for aggregate growth. In particular, we calculate that the relatively low local productivity growth in key regions lowered German output and welfare growth by a factor of two from 2010 to 2015.

Overall, we acknowledge that it remains difficult for policymakers to identify the key regions and sectors before they become too large and congested. Even if it were clear ex-ante which regions and sectors had the highest potential to positively affect the aggregate economy, it would still be difficult to pick the right policy instruments to push local productivity within those regions and sectors. Moreover, spatial development policies are probably not the best way to deal with the problem of congestion. The first-best policy is to address the market failures directly, which hamper investments in existing local structures that drive up local rents and limit the growth of the most productive regions.

Appendix 2.A Equilibrium conditions and solution algorithm

Equilibrium in changes. We briefly describe the equilibrium conditions in relative terms and the solution mechanism for the equilibrium expressed in changes. Similar to the main text, we define the change of a variable $\hat{y} \equiv y'/y$. Using the free mobility condition $U = (r_n H_n/L_n + w_n - s_n)/P_n$ and the equilibrium condition on input costs, $r_n \frac{H_n}{L_n} = \frac{\beta_n}{1-\beta_n} w_n$, we can rewrite labor demand L_n as

$$L_n = H_n \left(\frac{\omega_n}{P_n U + s_n} \right)^{1/\beta_n} \tag{2.A.1}$$

where $s_n = S_n/L_n$ is the per capita imbalance. In relative terms, the change in labor yields:

$$\hat{L}_n = \left(\hat{\omega}_n \frac{P_n U + s_n}{P_n' U' + s_n'} \right)^{1/\beta_n}. \tag{2.A.2}$$

A little algebra yields:

$$\frac{P_n' U' + s_n'}{P_n U + s_n} = \varphi_n \hat{P}_n \hat{U} + (1 - \varphi_n) \hat{s}_n, \tag{2.A.3}$$

where we define $\varphi_n \equiv 1/\left(1 + \frac{s_n}{P_n U}\right)$. Hence, for the change in labor, L_n we obtain:

$$\hat{L}_n = \left(\frac{\hat{\omega}_n}{\varphi_n \hat{P}_n \hat{U} + (1 - \psi) \hat{s}_n} \right)^{1/\beta_n}. \tag{2.A.4}$$

We can use this relationship to derive an expression for the change in indirect utility. Starting with the free mobility condition

$$U = \frac{\omega_n}{P_n} \left(\frac{H_n}{L_n} \right)^{\beta_n} - \frac{s_n}{P_n} \tag{2.A.5}$$

and noting that with $\hat{H}_n \equiv 1$ the relative change can be determined as

$$\hat{U} = \frac{1}{\varphi_n} \frac{\hat{\omega}_n}{\hat{P}_n} \left(\hat{L}_n \right)^{-\beta_n} - \frac{1 - \psi}{\psi} \frac{\hat{s}_n}{\hat{P}_n}. \tag{2.A.6}$$

We can use the labor condition that $L = \sum_{n=1}^{N} L_n \hat{L}_n$, which gives under the condition that labor $L \equiv 1$

$$\hat{L}_n = \frac{\hat{L}_n}{L} = \frac{\left(\frac{\hat{\omega}_n}{\varphi_n \hat{P}_n \hat{U} + (1-\psi) \hat{b}_n} \right)^{1/\beta_n}}{\sum_{i=1}^{N} L_i \left(\frac{\hat{\omega}_i}{\psi_i \hat{P}_i \hat{U} + (1-\psi) \hat{b}_i} \right)^{1/\beta_i}} L. \tag{2.A.7}$$

Under the condition $\hat{U} L = \sum_{n=1}^{N} \hat{U} L_n \hat{L}_n$, the change in the indirect utility becomes:

$$\hat{U} = \frac{1}{L} \sum_n L_n \hat{L}_n \left(\frac{1}{\varphi_n} \frac{\hat{\omega}_n}{\hat{P}_n} \left(\hat{L}_n \right)^{-\beta_n} - \frac{1 - \varphi_n}{\varphi_n} \frac{\hat{s}_n}{\hat{P}_n} \right). \tag{2.A.8}$$

Market clearing for final goods implies that:

$$X_n^{j'} = \alpha^j \left(\hat{\omega}_n \left(\hat{L}_n \right)^{1-\beta_n} \omega_n H_n^{\beta_n} \left(L_n \right)^{1-\beta_n} - S_n' \right) + \sum_{k=1}^{J} \gamma_n^{kj} \sum_{i=1}^{N} \pi_{in}^{k\prime} X_i^{k\prime}. \tag{2.A.9}$$

Using the condition that $\omega_n H_n^{\beta_n} L_n^{1-\beta_n} = I_n L_n + S_n$, we can rewrite the condition as:

$$X_n^{j\prime} = \alpha^j \left(\hat{\omega}_n \left(\hat{L}_n \right)^{1-\beta_n} [I_n L_n + S_n] - S_n^{\prime} \right) + \sum_{k=1}^{J} \gamma_n^{kj} \sum_{i=1}^{N} \pi_{in}^{k\prime} X_i^{k\prime}. \tag{2.A.10}$$

Using the trade balance condition gives the relationship for the changes in factor prices:

$$\hat{\omega}_n \left(\hat{L}_n \right)^{1-\beta_n} \omega_n H_n^{\beta_n} (L_n)^{1-\beta_n} = \sum_{j=1}^{J} \gamma_n^j \sum_{i=1}^{N} \pi_{in}^{j\prime} X_i^{j\prime}. \tag{2.A.11}$$

Solution algorithm. Having determined the expressions for changes in labor and indirect utility, we consider next an exogenous change in fundamental productivity, $\hat{T}_n^j$. We apply the following iterative solution mechanism to solve for the counterfactual equilibrium. The derived set of unknowns is of size $2N+3JN+JN^2$, where specifically $\hat{\omega}_n(N)$, $\hat{L}_n(N)$, $X_i^{j\prime}(JN)$, $\hat{P}_n^j(JN)$, $\pi_{ni}^{j\prime}(JN^2)$ and $\hat{x}_n^j(JN)$. In step (1), we start by guessing a new vector of factor prices $\hat{\boldsymbol{\omega}}$.

Step 1: Obtain prices $\hat{P}_n^j$ and input costs $\hat{x}_n^j$ which are consistent with the changes in input costs (JN equations), $\hat{\boldsymbol{\omega}}$, which implies

$$\hat{x}_n^j = (\hat{\omega}_n)^{\gamma_n^j} \prod_{k=1}^{J} \left(\hat{P}_n^k \right)^{\gamma_n^{jk}} \tag{2.A.12}$$

and the changes in the aggregate price index (JN equations)

$$\hat{P}_n^j = \left(\sum_{j=1}^{J} \pi_{ni}^j \left[\hat{\kappa}_{ni}^j \hat{x}_i^j \right]^{-\theta^j} \hat{T}_n^{j\,\theta^j \gamma_n^j} \right)^{-1/\theta^j} \tag{2.A.13}$$

Step 2: Solve for the trade shares, $\left(\pi_{ni}^{\prime j} \right)$ (JN^2 equations), which are consistent with the change in factor prices given $\hat{P}_n^j(\hat{\boldsymbol{\omega}})$ and $\hat{x}_n^j(\hat{\boldsymbol{\omega}})$ using the relationship

$$\pi_{ni}^{\prime j} = \pi_{ni}^j \left(\frac{\hat{x}_i^j}{\hat{P}_n^j} \hat{\kappa}_{ni}^j \right)^{-\theta^j} \hat{T}_n^{j\,\theta^j \gamma_i^j} \tag{2.A.14}$$

Step 3: Solve for labor changes across regions, which are consistent with the change in factor prices given $\hat{P}_n^j(\hat{\boldsymbol{\omega}})$ and $\hat{x}_n^j(\hat{\boldsymbol{\omega}})$ using the labor mobility condition (N equations)

$$\hat{L}_n = \frac{\hat{H}_n \left(\frac{\hat{\omega}_n}{\varphi_n \hat{P}_n \hat{U} + (1-\psi) \hat{b}_n} \right)^{1/\beta_n}}{\sum_{i=1}^{N} L_i \hat{H}_i \left(\frac{\hat{\omega}_i}{\psi_i \hat{P}_i \hat{U} + (1-\psi) \hat{b}_i} \right)^{1/\beta_i}} L, \tag{2.A.15}$$

where the change in land and structures is set to $\hat{H}_n = 1$, $\forall n \in N$, and the change in indirect utility can be expressed by $\hat{U} = \frac{1}{L} \sum_n L_n \left(\frac{1}{\varphi_n} \frac{\hat{\omega}_n}{\hat{P}_n} \left(\hat{L}_n \right)^{1-\beta_n} - \frac{1-\varphi_n}{\varphi_n} \frac{\hat{L}_n \hat{b}_n}{\hat{P}_n} \right)$. Further, we have $\hat{b}_n = \frac{u_n^{\prime} + s_n^{\prime}}{u_n + s_n}$, $\psi = \frac{1}{1 + \frac{\Gamma_n + S_n}{L_n I_n}}$ and calculate the change in the aggregate price index as a weighted product of the sector-specific changes, where

$$\hat{P}_n = \prod_{j=1}^{J} \left(\hat{P}_n^j \right)^{\alpha^j}. \tag{2.A.16}$$

Step 4: Solve for the respective expenditure, which is consistent with the changes in factor prices using the regional market clearing condition in final goods (JN equations)

$$X_n^{j\prime} = \sum_{k=1}^{J} \gamma_n^{k,j} \left(\sum_{i=1}^{N} \pi_{in}^{k\prime} X_i^{k\prime} \right) + \alpha^j \left(\hat{\omega}_n \left(\hat{L}_n \right)^{1-\beta_n} (I_n L_n + \Gamma_n + S_n) - S_n^{\prime} - \Gamma_n^{\prime} \right) \tag{2.A.17}$$

which as a result yields a set of $N \times J$ equations in an equal number of unknowns, given by $\left\{ X_n^{j'}(\hat{\boldsymbol{\omega}}) \right\}_{N \times J}$. To solve for this expression, we use matrix inversion.

Step 5: Update the guess for the change in factor prices, $\hat{\omega}_n^*$ using the relationship

$$\hat{\omega}_n = \frac{\gamma_n^j \sum_i (\pi_{in})'(\hat{\boldsymbol{\omega}}) X_i^{j'}(\hat{\boldsymbol{\omega}})}{\hat{L}_n(\hat{\boldsymbol{\omega}})^{1-\beta_n}(L_n I_n + \Gamma_n + S_n)} \tag{2.A.18}$$

Iterate over Step 1 to Step 5 until achieving convergence in the sense $\|\boldsymbol{\omega}^* - \hat{\boldsymbol{\omega}}\| < \epsilon$, where ϵ denotes the tolerance level.

Appendix 2.B Channels for TFP, real GDP and welfare

The logarithm of TFP, $\ln A_n^j$, is defined as the difference of real gross output and the input bundles, that is

$$\ln A_n^j = \ln \left(\frac{w_n L_n^j + r_n H_n^j + \sum_{k=1}^{J} P_n^k M_n^{jk}}{P_n^j} \right) - (1-\beta_n)\gamma_n^j \ln L_n^j - \beta_n \gamma_n^j \ln H_n^j - \sum_{k=1}^{J} \gamma_n^{jk} \ln M_n^{jk}. \tag{2.B.1}$$

We can write

$$Y_n^j = w_n L_n^j + r_n H_n^j + \sum_{k=1}^{J} P_n^j M_n^{jk} = \frac{w_n L_n^j}{\gamma_n^j (1-\beta_n)} \tag{2.B.2}$$

We know that real GDP is the difference between real gross output and expenditures on materials. Changes in real GDP are calculated as $\widehat{\text{GDP}}_n^j = \ln(\hat{w}_n) + \ln(\hat{L}_n^j) - \ln(\hat{P}_n^j)$, using the relationship $\hat{P}_n^j = [\hat{\pi}_{nn}^j]^{1/\theta} \hat{x}_n^j [\hat{T}_n^j]^{-\gamma_i^j}$.

Appendix 2.C Data

Table 2.4 in this appendix displays the different data sources. Bilateral trade flows on the region-sector level comes from the Forecast of Nationwide Transport Relations in Germany 2030 (VVP). The VVP data were collected in a project undertaken by Intraplan Consulting, Munich, in collaboration with BVU Consulting, Freiburg, for the Federal Ministry of Transport and Digital Infrastructure and is only available for 2010. The data are made available through the Institute for Transport Research of the German Aerospace Center under the link `http://daten.clearingstelle-verkehr.de/276/`.

The data contain bilateral trade volumes in metric tons at the product level by transport mode (road, rail, water) that went through German territory in 2010. We aggregate trade flows to the $N = 402$ German administrative districts (Kreise and kreisfreie Städte) and across transport modes at the 1-digit level of the ISIC Revision 4 classification. We convert the original NST2007 product scheme provided by the VVP to the ISIC Revision 4 classification at the 1-digit

Table 2.4: Overview of the Data Sources and Variables

Bilateral trade flows (region-region-sector level)	Forecast of Nationwide Transport Relations in Germany 2030 (VVP)
Industry output (sector level)	World Input-Output Database (WIOD)
Input-Output linkages (sector level)	World Input-Output Database (WIOD)
Value-added (region-sector level)	Eurostat
Employment (region-sector level)	Eurostat
Wage (region level)	INKAR Database

Notes: This table reports the different data sources used in the model.

level.[29] Moreover, we convert trade volumes to trade values by using appropriate unit values. We match aggregate trade flows in metric tons to output per region and sector in millions of euro and calculate the corresponding unit values. Using the unit values per region-sector pair together with information on region-sector specific trade volumes from the VVP we can match region-sector-specific gross output.

We also use data on nominal wages, region-sector specific employment, and output. Data for employment and wage income for each region come from Eurostat (Eurostat, 2016) and the INKAR Database (NUTS-3 level, see INKAR, 2016). We normalize employment, to sum up to one. We use the information on sector-specific output and input-output linkages from the World Input-Output Tables (WIOD, see Timmer et al., 2015). We allocate sector-specific output across regions according to region-specific employment shares. Information on sector-region specific value-added comes from Eurostat.

To classify all data according to a unique classification scheme, we use the ISIC Rev. 1 scheme. We transfer the trade data to this classification scheme relying on official correspondence tables provided by EU Ramon accessible under `http://ec.europa.eu/eurostat/ramon/relations/index.cfm?TargetUrl=LST_REL`.
Throughout the analysis, we rely on estimates for sector-specific trade elasticities from Caliendo and Parro (2015). Table 2.6 displays the respective values.

Panel (a) of Figure 2.6 shows the relationship between predicted and observed trade imbalances. We find trade surpluses of up to 11.01 billion euro for Munich (Landeshauptstadt), Berlin, Düsseldorf (kreisfreie Stadt) and Frankfurt am Main (kreisfreie Stadt), while Freising, Duisburg (kreisfreie Stadt) and Bielefeld (kreisfreie Stadt) are among the districts with the largest trade deficits between 2.73 and 4.45 billion euro. The observed imbalances, which are significant in size, justify our modeling of the national portfolio.

Panel (b) reveals that regions with a trade surplus are net contributors to the national portfolio, while regions with trade deficits are net recipients. To see this, we calculate the transfer rate, which is defined as the region n's income after redistribution relative to the income before redistribution. A transfer rate larger than one identifies regions as net recipients, values less than one as net donors.[30] The contribution share ι_n determines whether a region is a net donor or recipient. Given the observed trade imbalances and labor shares, some regions contribute all their rents to the national portfolio, while others make no contributions at all. For example, Ludwigshafen (kreisfreie Stadt) and Leverkusen (kreisfreie Stadt) have a contribution share of $\iota_n = 1$, while Mecklenburgische Seenplatte and Vulkaneifel (Daun, Landkreis) make no

[29] NST is the abbreviation for 'Nomenclature uniforme des marchandises pour les statistiques de transport'. This system represents a standard classification for transport statistics for goods transported by road, rail, inland waterways, and sea (maritime) at the European level since 2008 and is based on the classifications of products by activity (CPA). See Henkel and Seidel (2019) and Henkel et al. (2019) for more details about the dataset.

[30] Formally, the transfer rate is calculated as $\eta_n = [w_n L_n + \chi L_n + (1 - \iota_n) r_n H_n] / (w_n L_n + r_n H_n)$, where $\chi = \sum_i \iota_i r_i H_i / L$ denotes the per capita receipts from the national portfolio, $w_n L_n$ reflects region n's wage income and $\iota_n r_n H_n$ defines the income from land and structures that is not distributed to the national portfolio.

Table 2.5: ISIC Revision 4 Sector Classification

Classification ISIC Rev. 4	**Sector**	**Description**
A	A	Agriculture, Forestry and Fishing
B, D and E	B,D,E	Mining and Quarrying Electricity, Gas, Steam and Air Conditioning Supply Water Supply; Sewerage, Waste Management and Remediation Activities
C	C	Manufacturing (e.g., Wood and of Products of Wood and Cork, except Furniture, Chemicals and Chemical products, Basic Pharmaceutical Products and Pharmaceutical Preparations, Rubber and Plastics Products, Electrical Equipment)
F	F	Construction (Construction of Buildings, Civil Engineering, Specialized Construction Activities
G, H and I	G−J	Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles Transportation and Storage Accommodation and food service activities
J		Information and Communication (e.g., Publishing activities)
K	K−N	Financial and Insurance activities
L		Real Estate Activities (Real Estate Activities with own or leased Property)
M and N		Professional, Scientific and Technical Activities (e.g., Legal and Accounting Activities), Administrative and Support Service Activities
O, P and Q	O−U	Public Administration and Defense; Compulsory Social Security Education, Human Health and Social Work Activities
R, S, T and U		Arts, Entertainment and Recreation Other service activities

Notes: This table displays the seven sectors: *Agriculture* (A), *Mining* (B/D/E), *Manufacturing* (C) and *Wholesale/Retail Trade* (G−J), *Construction* (F), *Financial and Insurance* (K−N) and *Public Administration/Defense/Education* (O−U). Sectors 1−4 are tradable sectors, sectors 5−7 non-tradable sectors.

Table 2.6: Trade Elasticity θ^j, by sector

Tradable Sector	ISIC Rev.4 Classification	Trade Elasticity θ^j
Agriculture, Forestry, Fishing	A	8.59
Mining/Quarrying, Electricity, Gas, Steam	B,D,E	14.83
Manufacturing	C	9.23
Wholesale/Retail Trade	G−J	8.04

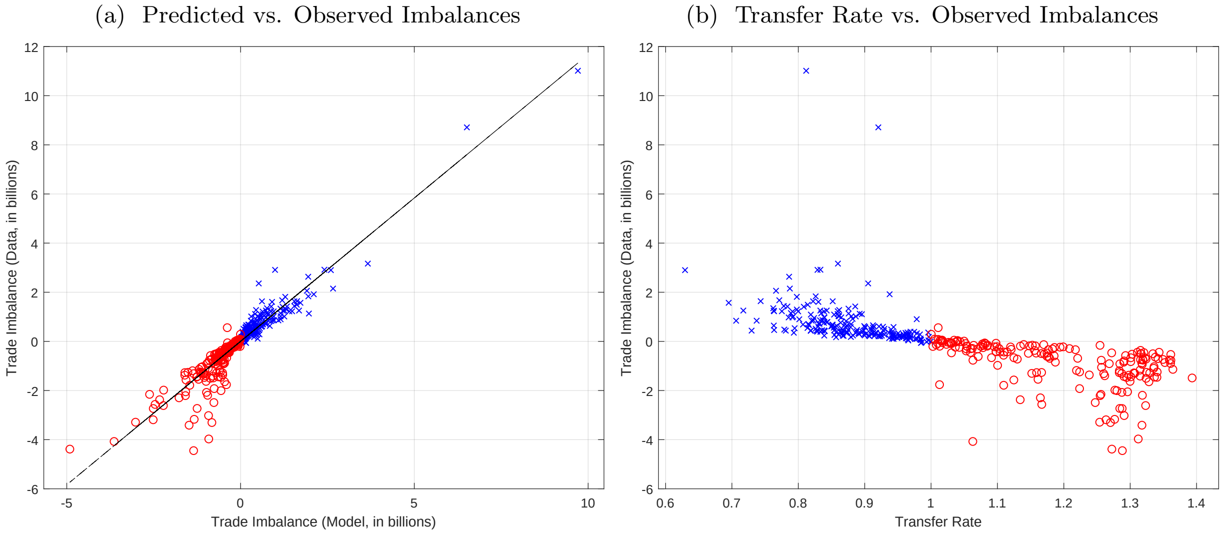
Notes: This table displays the sectoral dispersion of productivity, θ^j for tradable sectors. The values are based on Caliendo and Parro (2015). For the non-tradable sectors we assume a trade elasticity of $\theta^j = 4.55$.

contributions at all. Outliers are the big cities Hamburg and Munich (Landkreis), which have both substantial trade surpluses and large local rents. For them, only small contribution shares ι_n are sufficient to match the trade imbalances in the model to the data.

Appendix 2.D Aggregation of TFP and real GDP

Regional, sectoral, and aggregate TFP. This section entails the aggregation steps of TFP and real GDP to sectoral, regional, and national aggregates. The TFP aggregates are weighted by the region-specific or sector-specific gross output shares. Specifically, the weighting factors include $w_n L_n^j$ and $\gamma_n^j(1-\beta_n)$. On the other hand, for the real GDP aggregates, we use the

Figure 2.6: Trade Imbalances and Contributions to the National Portfolio



Notes: Panel (a) plots predicted against observed trade imbalances between German NUTS-3 regions in 2010. Panel (b) shows how the observed imbalances relate to transfer rates. Note that net donors (with trade surpluses) have a transfer rate below one and are marked by crosses (in blue). Similarly, net recipients (with trade deficits) are identified by transfer rates above one and are marked by circles (in red).

respective value-added shares. For the regional TFP changes, we obtain:

$$\hat{A}_n = \sum_{j=1}^{J} \left(\frac{Y_n^j}{\sum_{j=1}^{J} Y_n^j} \right) \hat{A}_n^j = \sum_{j=1}^{J} \left(\frac{\frac{w_n L_n^j}{\gamma_n^j (1-\beta_n)}}{\sum_{j=1}^{J} \frac{w_n L_n^j}{\gamma_n^j (1-\beta_n)}} \right) \hat{A}_n^j. \tag{2.D.1}$$

The corresponding sector-specific TFP aggregate reads:

$$\hat{A}^j = \sum_{n=1}^{N} \left(\frac{Y_n^j}{\sum_{n=1}^{N} Y_n^j} \right) \hat{A}_n^j = \sum_{n=1}^{N} \left(\frac{\frac{w_n L_n^j}{\gamma_n^j (1-\beta_n)}}{\sum_{n=1}^{N} \frac{w_n L_n^j}{\gamma_n^j (1-\beta_n)}} \right) \hat{A}_n^j. \tag{2.D.2}$$

To derive the national aggregate, we sum over both dimensions and arrive at:

$$\hat{A} = \sum_{n=1}^{N} \sum_{j=1}^{J} \left(\frac{Y_n^j}{\sum_{j=1}^{J} Y_n^j} \right) \hat{A}_n^j = \sum_{n=1}^{N} \sum_{j=1}^{J} \left(\frac{\frac{w_n L_n^j}{\gamma_n^j (1-\beta_n)}}{\sum_{j=1}^{J} \frac{w_n L_n^j}{\gamma_n^j (1-\beta_n)}} \right) \hat{A}_n^j. \tag{2.D.3}$$

Regional, sectoral, and aggregate real GDP. The aggregation procedure for real GDP is similar except for the weighting, which relies on value-added measures. Respective value-added measures are given for sectors and regions, respectively by

$$\lambda_n^j = \frac{w_n L_n^j + r_n H_n^j}{\sum_j (w_n L_n^j + r_n H_n^j)} \quad \text{and} \quad \epsilon_n^j = \frac{w_n L_n^j + r_n H_n^j}{\sum_n (w_n L_n^j + r_n H_n^j)} \tag{2.D.4}$$

The regional change in real GDP can be determined by:

$$\widehat{\text{GDP}}_n = \sum_j \lambda_n^j \widehat{\text{GDP}}_n^j. \tag{2.D.5}$$

Similarly, the sectoral aggregate reads:

$$\widehat{\text{GDP}}_j = \sum_n \epsilon_n^j \widehat{\text{GDP}}_n^j. \tag{2.D.6}$$

The national aggregate can be written as:

$$\widehat{\text{GDP}} = \sum_j \sum_n \frac{w_n L_n^j + r_n H_n^j}{\sum_j \sum_n (w_n L_n^j + r_n H_n^j)} \widehat{\text{GDP}}_n^j. \tag{2.D.7}$$

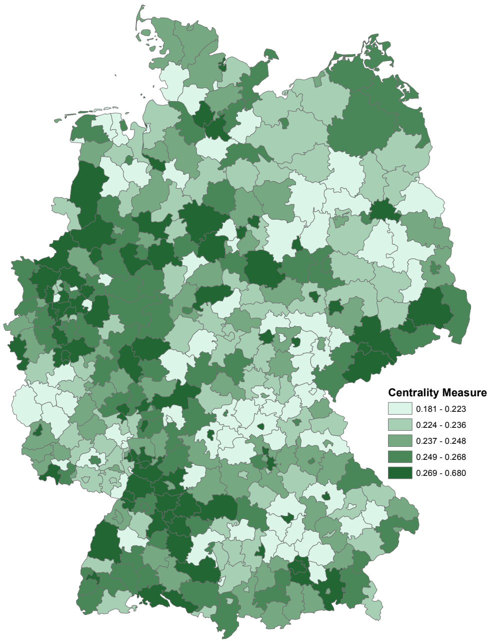
Appendix 2.E Counterfactual results: The key regions

Table 2.7: Key and Bottom Regions

	Distribution and Key Regions		
	(a) $\text{TFP}^{elast.}$	(b) Real $\text{GDP}^{elast.}$	(c) $\text{Welfare}^{elast.}$
Rank 1	Ludwigshafen a.R.	Salzgitter	Ludwigshafen a.R.
Rank 2	Wiesbaden (Lhauptstadt)	Nürnberg	Bodenseekreis
Rank 3	Hochtaunuskreis	Dingolfing-Landau	Ingolstadt
Rank 4	Leverkusen	Mannheim	Leverkusen
Rank 5	Düsseldorf	Speyer	Schweinfurt
Rank 6	Münster	Rastatt	Erlangen
Rank 7	Munich (Lhaupstadt)	Krefeld	Tuttlingen
Rank 8	Starnberg	Bielefeld	Ostalbkreis
Rank 9	Darmstadt	Herne	Altoetting
Rank 10	Bodenseekreis	Kassel	Rottweil
Rank 11	Ingolstadt	Freising	Hochtaunuskreis
Rank 12	Wuppertal	Hagen	Biberach
Rank 13	Bonn	Heidenheim	Wiesbaden (Lhauptstadt)
Rank 14	Erlangen	Ulm	Munich (Lhauptstadt)
Rank 15	Wesermarsch	Schweinfurt	Wuppertal
...	...	...	...
Rank 388	Kyffhaeuserkreis	Landkreis Rostock	Neuburg-Schrobenhausen
Rank 389	Vogelsbergkreis	Spree-Neise Kreis	Saale-Orla-Kreis
Rank 390	Hassberge	Würzburg	Cuxhaven
Rank 391	Greiz	Cochem-Zell	Neumarkt i.d.Opf.
Rank 392	Bottrop	Rendsburg-Eckernfoerde	Pfaffenhofen a.d.Ilm
Rank 393	Zwickau	Altenburger Land	Harburg
Rank 394	Bad Kissingen	Harburg	Saalekreis
Rank 395	Ostprignitz-Ruppin	Cuxhaven	Rendsburg-Eckernfoerde
Rank 396	Eichsfeld	Wittmund	Mainz-Bingen
Rank 397	Saale-Holzland	Leer	Würzburg
Rank 398	Altenburger Land	Ludwigslust-Parchim	Cloppenburg
Rank 399	Saale-Orla Kreis	Steinburg	Günzburg
Rank 400	Ludwigslust-Parchim	Havelland	Schweinfurt
Rank 401	Eisenach	Schweinfurt	Steinburg
Rank 402	Havelland	Dahme-Spreefeld	Dahme-Spreefeld

Notes: This table displays the respective 15 key regions and bottom regions of in terms (a) TFP elasticity, (b) real GDP elasticity and (c) welfare elasticity.

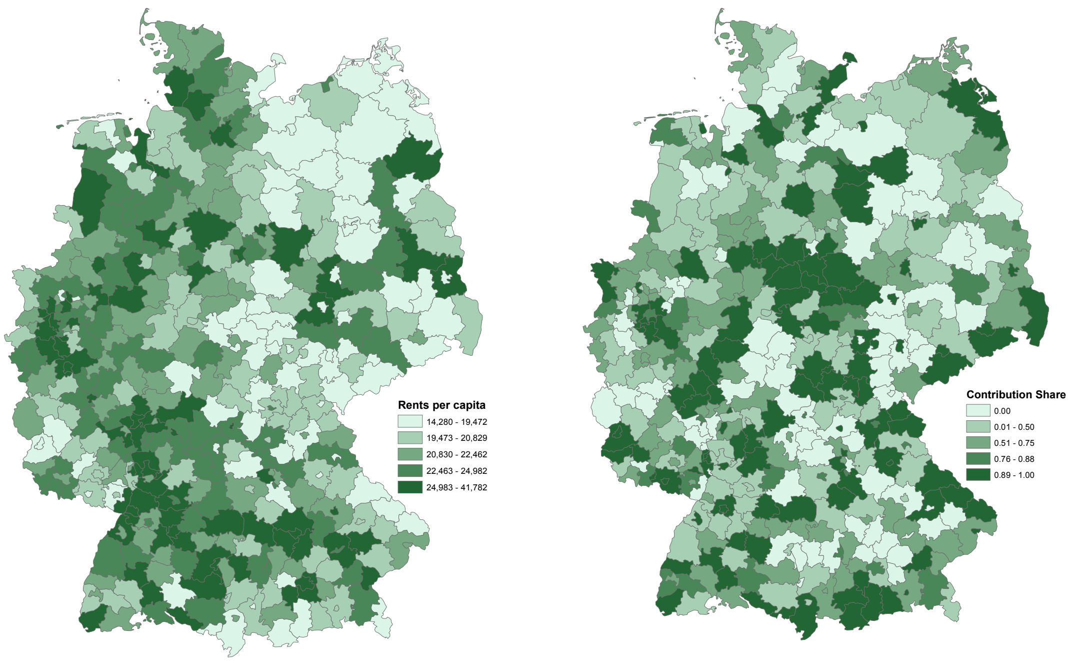
Figure 2.7: Centrality Measure (in Hundreds)



Notes: This figure depicts the 'centrality' measure (in hundreds) per region. A darker shading indicates higher values.

Figure 2.8: Local Rents and National Portfolio

(a) Rents per capita (b) Contribution Share



Notes: This figure plots the rents per capita (in euro) and the contribution share ι_n. A darker shading indicates higher values.

The model framework allows us to determine local rents per capita. They reflect the value-added by land and structures relative to local labor L_n. Panel (a) of Figure 2.8 displays the values. Panel (b) of Figure 2.8 shows the estimated contribution share ι_n. The contribution share determined to minimize the sum of squared residuals $\sum_{i=1}^{N}(\Gamma_n^M - \Gamma_n^D)^2$, where Γ_n^M reflects the model induced imbalances, Γ_n^D represents the data induced balances and the estimated shares are subject to the constraint $\iota_n \in [0,1]$.

Appendix 2.F Decomposing the aggregate effects

In the main text, we have emphasized the aggregate effects of local productivity changes. However, in general equilibrium, there is a direct effect of local productivity changes, and spillover effects via spatial linkages to other markets. Both effects then add up to the aggregate effect of a local productivity change in the economy. To highlight the relative importance of local and spillover effects for the aggregate effects on TFP and real GDP we follow Acemoglu et al. (2015), Adao et al. (2019), and Hsieh and Moretti (2019) and decompose the aggregate effects into local and corresponding spillover effects. The latter is a compound of all spillover effects in all other region-sectors pairs that were not hit by a direct local productivity shock. Changes in aggregate TFP can be written as follows:

$$\widehat{A} = \underbrace{\frac{Y_n}{Y}\hat{A}_n}_{\text{local effect}} + \underbrace{\sum_{i \neq n}\frac{Y_i}{Y}\hat{A}_i}_{\text{spillover effects}} , \tag{2.F.1}$$

where Y_n/Y represents the region-specific gross output share of region n, and $\hat{A}_n$ is the change in productivity (TFP) in the region. For real GDP, we obtain:

$$\widehat{GDP} = \underbrace{\frac{VA_n}{VA}\widehat{GDP}_n}_{\text{local effect}} + \underbrace{\sum_{i \neq n}\frac{VA_i}{VA}\widehat{GDP}_i}_{\text{spillover effects}}, \tag{2.F.2}$$

where region-specific value-added shares VA_n/VA weight the specific local changes in real GDP.[31]

We proceed in three steps. First, we determine the importance of spillover effects for the aggregate effects. We calculate the spillover effects as the difference between the aggregate and local effects for the affected region n. Second, we determine the relative importance of the local and spillover effects (in percentage point changes) by calculating their respective ratios. Having found that spillover effects play a major role, in a third step, we focus on the role of spatial linkages and labor mobility on aggregate changes.

Spillover effects. We find that the spillover effects make up for the largest part of the aggregate effect. Between 95.26 percent and 99.56 percent of the aggregate change in real GDP comes from output changes in regions not hit by the local productivity shock. A local productivity shock in one region only has a small effect in each other region, but the total of all spillover effects is a weighted average of a large set of regions $N-1$ that also constitute a larger fraction of total value-added or gross output. Hence, neglecting the impact of spillover effects would lead us to tremendously understate the aggregate effects of local productivity changes in our analysis.

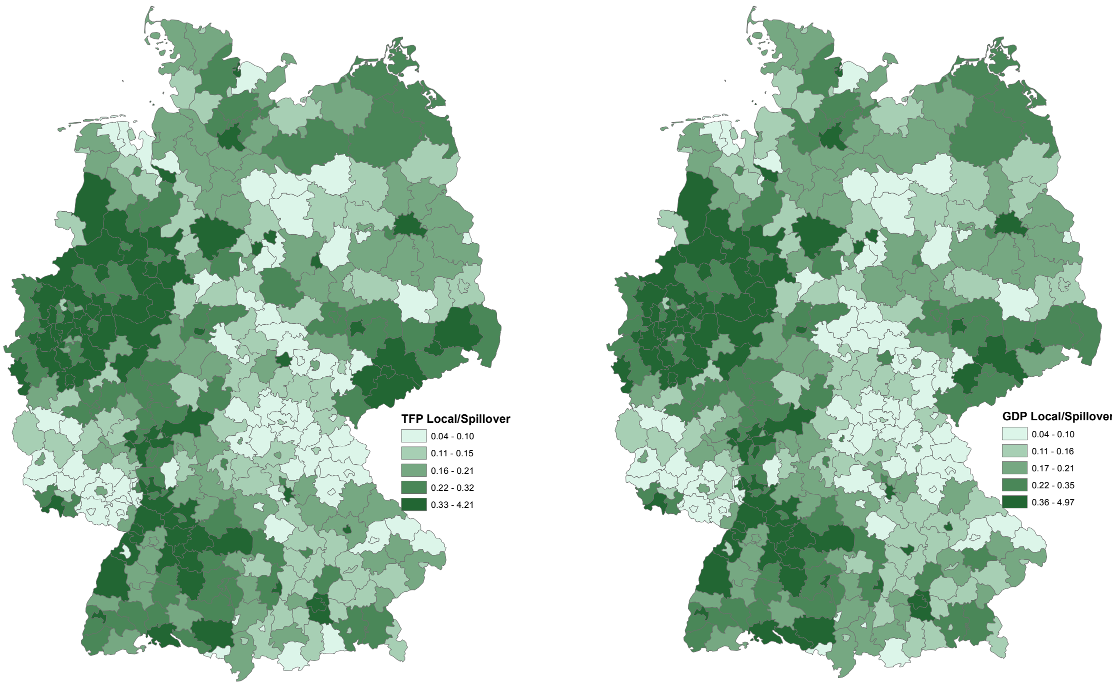
Local versus spillover effects. Panel (a) and Panel (b) in Figure 2.9 display the relative importance of local and spillover effects for TFP and real GDP. We find large geographical heterogeneity in the relative importance of the local and spillover effects. The different panels show that local TFP effects are most important in cities like Berlin (4.21 percent) and Ham-

[31] Note, $VA_n/VA = \sum_j \left(w_n L_n^j + r_n H_n\right) / \sum_n \sum_j \left(w_n L_n^j + r_n H_n\right)$.

burg (3.03 percent) (in hundreds). The relative importance of the local real GDP effect is also pronounced for Berlin and Hamburg with 4.97 percent and 3.47 percent (in hundreds). On average, high gross output (Y_n/Y) and value-added shares VA_n/VA are a sufficient statistic for strong local effects relative to spillovers. Moreover, key regions with high aggregate elasticities (see Figure 2.1) also have high local relative to spillover effects. Large cities that constitute the economic centers, like Munich, Berlin, and Hamburg, also exert strong spillover effects to other less-congested regions, which still can attract a larger share of labor. This explains their high aggregate elasticities.[32] Thus, the impact of local productivity growth is positive everywhere, but the strength of the aggregate effects depend strongly on where productivity changes occur.

Figure 2.9: Relative Importance of the Local Effect, by Region

(a) TFP (in Hundreds) (b) GDP (in Hundreds)



Notes: Panel (a) plots the relative importance of the local effect to the aggregate for TFP and Panel (b) plots the relative importance of the local effect to the aggregate for GDP following a 10 percent productivity shock. The effects are measured in hundred percent. A darker shading indicates higher values.

Spatial linkages and labor mobility. To quantify the importance of spatial linkages and labor mobility for the aggregate effects, we repeat the same exercise from above but abstract from sectoral linkages and/or labor mobility across regions. We find that both the sectoral linkages and the mobility of labor are crucial for the relative size of local and spillover effects. To determine the importance of sectoral linkages, we set up a baseline economy without sectors, but all regions are still allowed to trade their intermediate goods with each other. To abstract

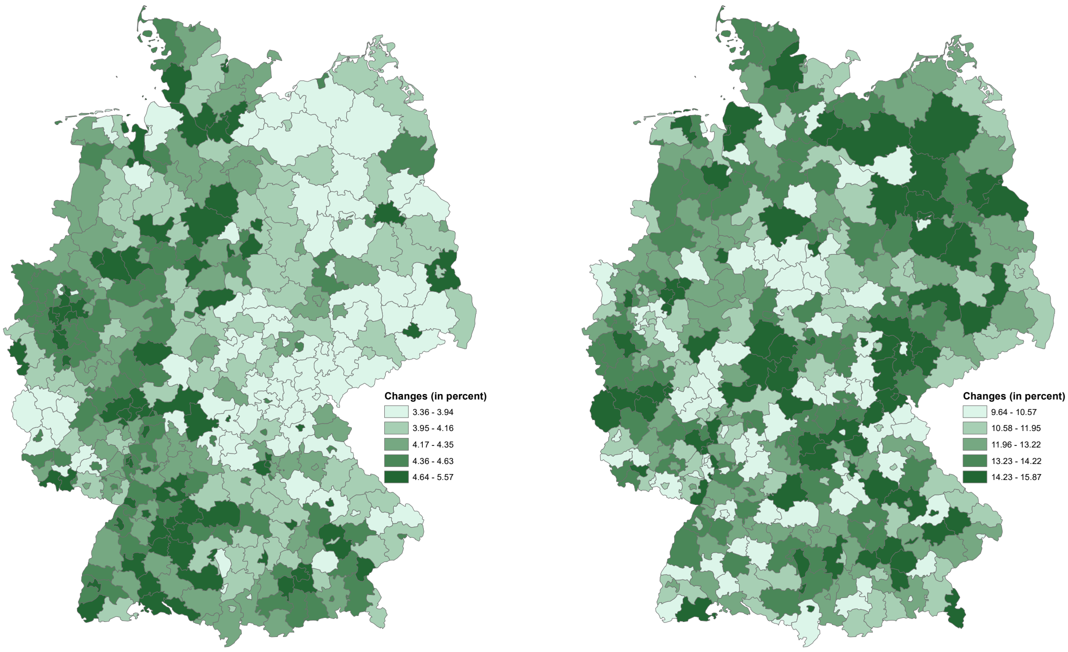
[32]Figure 2.10 in this appendix displays the unweighted changes in local TFP and local real GDP (measured in percent) arising from the local 10 percent productivity shock. Key regions concerning aggregate TFP have the highest unweighted local TFP effects, whereas for the respective key regions concerning real GDP the unweighted local effects are rather small. Relatively remote regions with a low degree of initial congestion have larger unweighted local GDP effects. For the key regions concerning real GDP the unweighted local effects, however, are scaled up by comparatively large local value-added shares VA_n/VA. This explains their relative large weighted local real GDP effects. For example, in Munich (Landeshauptstadt) the unweighted local GDP effect of 11.54 percent is scaled by a value-added share of 2.64 percent to a high local relative to the spillover effect of 3.08 percent.

from sectoral linkages we set the share of inputs used in different sectors to zero $\gamma_n^{jk} = 0$ and the share of value-added to one $\gamma_n^j = 1$. In this sense, all production comes from local value-added. We find similar aggregate elasticities compared to the baseline case with sectoral linkages.[33] In the absence of sectoral linkages, however, there are no spillovers to other sectors, which leads to more pronounced local effects relative to the spillovers. For the economic centers, we find a relative local TFP effect of 4.79 percent (in hundreds, compared to 4.21 percent in the baseline), while the respective relative local effect of GDP increases to 5.01 percent (in hundreds, compared to 4.97 percent in the baseline). The local productivity changes also have important effects on the economy through the mobility of labor. A positive productivity shock in one region attracts workers from other regions contributing to the positive local effect. To quantify the importance of labor mobility for the aggregate elasticities, we determine the relative size of local and spillover effects in a scenario without labor mobility. In technical terms, we get rid of the utility equalization condition and abstract from labor mobility across regions. We find that abstracting from the mobility of labor does not affect the pattern of aggregate TFP, but for aggregate GDP. The reason is that the importance of the local effect relative to the spillover effects decreases.

Figure 2.10: Unweighted Local Effects

(a) TFP Changes (in percent)

(b) GDP Changes (in percent)



Notes: This figure displays the unweighted own-region changes following a 10 percent productivity shock. Panel (a) displays the percentage changes in TFP, Panel (b) displays the percentage changes in real GDP.

[33] The full set of elasticities is available on request.

Appendix 2.G Data counterpart of measured TFP

To derive fundamental productivity changes $\hat{T}_n^j$, we first determine a data counterpart of the total factor productivity based on the model equation:

$$\ln\left(\hat{A}_n^j\right) = \ln\left(\widehat{\text{GDP}}_n^j\right) - \ln\left(\hat{L}_n^j\right) - \ln\left(\frac{\hat{w}_n}{\hat{x}_n^j}\right). \tag{2.G.1}$$

The estimation requires data on region-sector specific real GDP changes, employment changes, worker compensation changes and inflation data, all for 2010 and 2015.

Real GDP changes, $\widehat{\text{GDP}}_n^j$, are calculated by deflating nominal GDP data from Eurostat Regional Database by the respective price index.[34] Information about changes in employment, $\hat{L}_n^j$, comes from the Eurostat Regional Database (Eurostat, 2016), too. The change in nominal wages $\hat{w}_n^j$ is based on the average wage sum per region normalized by the national average of wages per sector w^j. The region-specific wage data comes from INKAR Database, the sector-specific data from Destatis (German Statistical Office, 2017). Finally, we need to determine the change in input costs, x_n^j. We exploit equation (4) and note first, that $\omega_n = \left(\frac{r_n}{\beta_n}\right)^{\beta_n}\left(\frac{w_n}{1-\beta_n}\right)^{1-\beta_n}$. We exploit this relationship noting that

$$r_n H_n = \frac{\beta_n}{1-\beta_n} w_n L_n \Longleftrightarrow \hat{r}_n \hat{H}_n = \hat{w}_n \hat{L}_n. \tag{2.G.2}$$

Together with a fixed supply of the local factor land and structures, $\hat{H}_n \equiv 1$ and a proportional relationship between local rents and total wages $\hat{r}_n = \hat{w}_n \hat{L}_n$, we obtain

$$\omega_n^{\gamma_n^j} = \left[\left(\frac{r_n}{\beta_n}\right)^{\beta_n}\left(\frac{w_n}{1-\beta_n}\right)^{1-\beta_n}\right]^{\gamma_n^j} \Longleftrightarrow \hat{\omega}_n^{\gamma_n^j} = \left[\hat{w}_n \hat{L}_n^{\beta_n}\right]^{\gamma_n^j}. \tag{2.G.3}$$

This relationship can be used to finally express the changes in input costs:

$$\hat{x}_n^j = \frac{(x_n^j)'}{x_n^j} = (\hat{\omega}_n)^{\gamma_n^j(1-\beta_n)} \prod_{k=1}^{J}\left(\hat{P}_n^j\right)^{\gamma_n^{jk}} = \left[\hat{w}_n \hat{L}_n^{\beta_n}\right]^{\gamma_n^j} \prod_{k=1}^{J}\left(\hat{P}_n^j\right)^{\gamma_n^{jk}}. \tag{2.G.4}$$

Taking the log of this equation, we obtain:

$$\ln(\hat{x}_n^j) = \gamma_n^j\left[\ln(\hat{w}_n) + \beta_n \ln(\hat{L}_n)\right] + \ln\left[\prod_{k=1}^{J}(\hat{P}_n^j)^{\gamma_n^{jk}}\right]. \tag{2.G.5}$$

With this we can finally calculate $\ln(\hat{w}_n/\hat{x}_n^j)$. We lack changes in region-sector input price data, $\hat{P}_n^j$. To circumvent this issue, we approximate respective input price changes. We simulate a scaling factor such that the composite of the consumer price changes and this scaling factor matches the change of aggregate multifactor productivity $\hat{A} = 1.0226$ as given by KLEMS data (Ark and Jäger, 2017) and sector-specific total factor productivity from Destatis (see German Statistical Office, 2017 and OECD, 2019). The respective minimization routine reads:

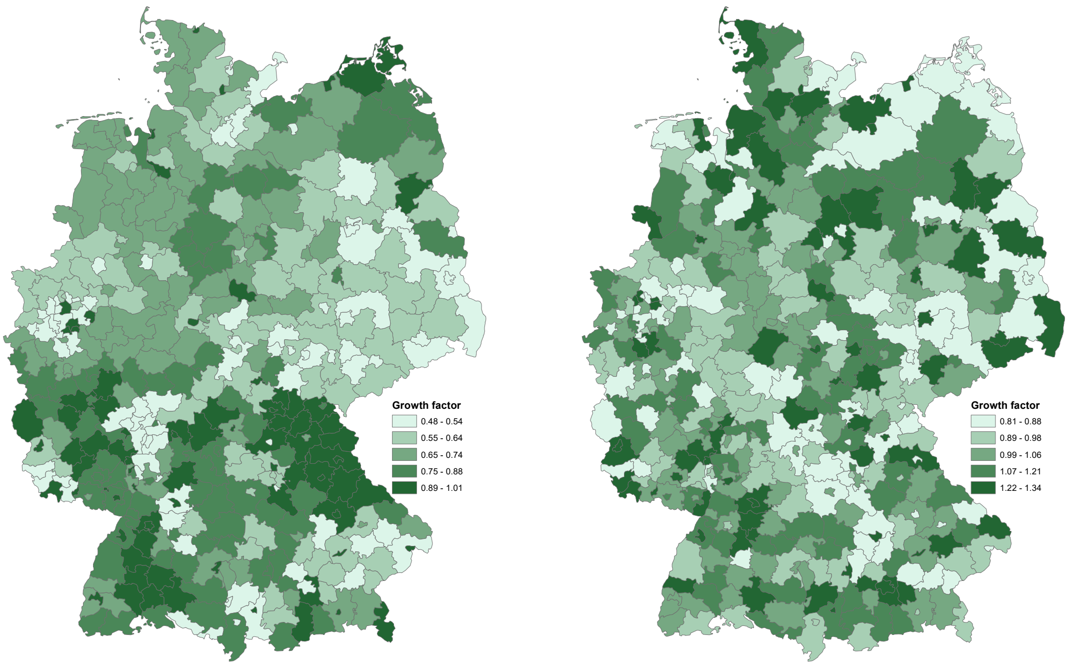
$$\underset{\hat{P}_n^j}{\arg\min}\left(1.0226 - \sum_j \sum_n \frac{Y_n^j}{Y}\hat{A}_n^j\right)^2 + \left(A^j - \sum_n \frac{Y_n^j}{Y_j}\hat{A}_n^j\right)^2, \tag{2.G.6}$$

[34] The data can be downloaded from `https://www.destatis.de/DE/ZahlenFakten/GesamtwirtschaftUmwelt/VGR/Inlandsprodukt/Tabellen/BruttoinlandVierteljahresdaten_xls.html`.

with the sector-specific total factor productivity changes from Destatis given by $A^j = [0.78, 0.96, 1.07, 1.06, 0.96, 1.01, 1.00]$ and Y_n^j/Y as the region-sector-specific gross output shares. The optimal $\hat{P}_n^j$ yield a perfect match for both constraints and are bounded between 0.9062 and 1.2812. Due to the structure of the data, the routine produces extreme values of $\hat{A}_n^j$. Hence, we winsorize the respective distribution and limit the extreme values to the 90th percentile and 10th percentile, respectively.

Figure 2.11: Predicted Changes in Productivity, $\hat{T}_n^j$

(a) Agriculture (b) Manufacturing



Notes: This figure plots the growth factors (< 1 reflects losses) in region-specific fundamental productivity $\hat{T}_n$ for (a) Agriculture and (b) Manufacturing. A darker shading indicates higher values. The plots for the remaining sectors are available upon request.

3 Integrated versus Segmented Markets

Abstract

In this paper, we build a general equilibrium model to study the implications of price integration on both firm-specific choices and the aggregate welfare of the economy. We relax the assumption of market segmentation by nesting a heterogeneous firm variant where each firm charges one price for all destination markets. Novel stochastic fixed costs lead to a continuous objective function and allow us to solve the model for an arbitrary number of destination markets. Our simulation studies show that firms in integrated markets charge lower prices, are less likely to export and earn lower expected profits than in segmented markets, hitting in particular low-productivity firms. Our simulation also shows that trade liberalization leads to higher welfare gains for integrated markets than under perfect segmentation, resulting from a more elaborate shift of resources towards more productive firms. These findings also hold for imperfect market integration.

3.1 Introduction

Over the last decades, the world has become increasingly integrated and globalized. In the period from World War II onward, countries have adopted more advanced technologies, have signed bilateral free-trade agreements, have formed customs unions and have organized themselves in single markets with a common currency.[1] The implemented measures have significantly reduced trade costs, quotas, and border checks. For example, between 1947 and 1994, worldwide tariffs have dropped on average by 80% (Huwart and Verdier, 2013). Further, there has been ongoing harmonization of norms and regulations, all leading to increasing bilateral trade flows in goods and services, and reductions in real trading and transaction costs (e.g., Anderton et al., 2007).

A large literature has analyzed the implications of market integration on consumer welfare and determined the presence of price integration by evaluating either single output sectors (Goldberg and Verboven, 2005), retail prices (Engel and Rogers, 2004) or price indices (Méjean and Schwellnus, 2009), finding consensus in two main results.[2] First, markets have benefited substantially from stronger competition between firms and improved allocation efficiency, both resulting from more transparent markets. Second, despite the growing downward pressure on prices, there is no empirical evidence for full price convergence across country borders, even for identical products.[3] In the case of the 'Economic and Monetary Union' (EMU), which belongs to the group of markets with the largest degree of integration, the price convergence starting in 1992 by announcing the common currency, the Euro, has slowed down after the introduction in 2002 (Méjean and Schwellnus, 2009).

The rationale behind price integration is straightforward. In integrated markets with perfect price transparency, eliminated exchange rate fluctuations, and low transaction costs, cross-border

[1] For a detailed overview, see Ilzkovitz et al. (2007) and Huwart and Verdier (2013). Well-known examples for common markets include, e.g., the European Union (EU); for free-trade agreements, e.g., the 'United States−Mexico−Canada Agreement' (USMCA), formerly known as the 'North American Free Trade Agreement' (NAFTA) between the United States (US), Canada, and Mexico (Caliendo and Parro, 2015).

[2] Donaldson (2015) provides an overview article on the gains from market integration.

[3] DellaVigna and Gentzkow (2019) distinguish between different markets in an intra-national context and find firms to charge almost uniform prices because of either managerial inertia or brand image concerns (see also McMillan, 2007; Orbach and Einav, 2007; Cho and Rust, 2010).

arbitrage may force firms to charge one price.[4] Inspired by these findings, two crucial questions in the light of proceeding market integration which we will address, are 'How would price integration affect the export decision of heterogeneous firms?' and 'What are its implications for the welfare of the aggregate economy?'

In this paper, we formalize the idea of price integration by extending the heterogeneous firms model pioneered by Melitz (2003). In its simplest form, this model nests fully integrated markets as edge knife case when bilateral trade costs are zero. To suggest a more realistic approach, our most important feature is to model a single-pricing decision for all markets allowing us to deviate from the pricing-to-market assumption. In this way, trade is still subject to bilateral trade costs accounting for observable trade frictions. This novel feature makes both the pricing rule and the market entry choice interdependent, i.e., instead of being market-specific, they are functions of wages, bilateral trade costs, market entry costs, and the export choice towards all markets. The export decision towards one market becomes itself a function of the price and thus depends on the characteristics of all markets, which displays market interdependence. The profit-maximizing price affects the decision of a firm producing in market i to enter market j.

The concept of interdependent market entry is rather new in the literature and has only been analyzed rarely; one example is the global sourcing context (Antràs et al., 2017), where firms choose the least cost source of supply to drive down sourcing costs. Most of the literature has assumed perfect segmentation of markets instead, which has simplified the analysis considerably because prices are a constant markup over marginal costs and include only information from the specific destination market.

This has avoided the so-called 'identification problem' of comparing 2^J cases to establish the optimal firm export structure. An innovative feature of our model is to solve the identification problem by assuming stochastic fixed costs. The stochastic notion of entry costs transforms the export decision into a probabilistic framework with a well-defined objective function and continuous first-order conditions. By the law of large numbers, we obtain the fraction of firms that serve a destination market. We circumvent to evaluate a binary export choice case-by-case and related numerical issues when solving this for a large number of markets.

In many other respects, we follow the standard heterogeneous firm model with monopolistic competition, where each firm produces a distinct variety with labor as a single input factor. The output good is sold to households, subject to bilateral iceberg trade costs. Despite the market interdependence, specific export choices continue to rely on non-negative profits for each market. Our approach achieves a high degree of flexibility as we nest integrated and segmented markets into a single framework. In this setup, we determine the impact of market integration on firm-specific decisions including pricing, export probabilities, and expected aggregate profits by relating the outcomes under integrated markets to their counterparts when assuming segmented markets. We also compare the outcomes for economic welfare and the equilibrium number of firms.

The interesting question is how a single-pricing mechanism affects firms and the aggregate welfare. Based on theoretical reasoning, price integration affects firms by imposing a second friction — besides bilateral trade costs — namely restrictions in the price-setting choice; thus lowering the number of profitable export markets compared to perfect segmentation. This follows directly from the composition of integrated prices as the mean of prices weighted by trade costs and market size. From an ex-ante point of view, this negatively affects the expected aggregate profits and should harm in particular low-productivity firms for which market entry costs are a larger concern.

To confirm our intuition and derive policy implications for firms and the aggregate economy, we use a stylized calibration of the model. In the first exercise, we show that firms (i) charge a lower price, (ii) are less likely to export and have (iii) lower expected aggregate profits; all

[4] The argument is closely related to the 'Purchasing Power Parity' (PPP), which states that when expressed in one currency, national prices should be equal. While there is some supportive evidence for relative PPP, this does not hold for absolute PPP (e.g., Rogoff, 1996; Goldberg and Knetter, 1997; Taylor and Taylor, 2004).

compared to segmented markets with pricing-to-market. In equilibrium, the number of firms is larger for integrated markets which reflects a lower productivity level, similar to Melitz (2003).

In a second exercise, we evaluate the effects of trade liberalization, cutting costs by between 2% and 10%, and thus making market entry profitable in particular for low-productivity firms. Therefore, the expected aggregate profits increase, too. We evaluate the ratio of prices, export share, and aggregate profits under integrated markets relative to segmented markets. We find that lower trade costs rise the ratios of prices, export exposure, and expected profits from values strictly less than one, to one. This implies that the price decline, as well as the increase of the export probability and the exports, are more than proportional for integrated markets. These patterns translate into higher welfare gains under perfect integration.

In the baseline scenario, welfare gains vary between 0.86% and 4.89%; the respective range for integrated markets is 0.73% and 4.33%. Whenever trade costs decline, less productive firms are profitable enough to potentially enter the market and demand fixed supply labor, which increases real wages, and thus, welfare. The pattern can also be explained by variable markups. A direct consequence of a common price at destination-specific marginal costs — they differ by the bilateral trade costs — are variable markups. This shifts the demand to markets with lower markups. The largest markup is in the domestic market since the domestic trade costs are normalized to one, while we set iceberg trade costs for other destination markets to 20%. Whenever trade costs decline, the demand for goods from market i shifts to consumers from foreign markets given the smaller markup. Yet, these goods are produced subject to bilateral iceberg trade costs.

In a final exercise, we quantify the impact of partial integration by adopting the single-pricing rule for a subset of markets, maintaining market-specific pricing for the remaining destinations. The welfare gains are of similar magnitude and are between the gains of segmented and integrated markets. The observed patterns are robust to asymmetries in either labor force, bilateral trade costs, or market entry costs.

Related Literature

Our paper adds to several strands of literature. First, our paper contributes to the literature on heterogeneous firms and extensions thereof (Antràs and Helpman, 2004; Helpman et al., 2008; Arkolakis et al., 2008; Bernard et al., 2011; Melitz and Ottaviano, 2008). We deviate by setting up a model with unique pricing and stochastic fixed costs, which allows every firm to export with a given probability.

Second, we contribute to a growing literature that models firm decisions in an interdependent market setting and suggests applicable solution strategies. Yeaple (2003) and Grossman et al. (2006) have first described the inherent difficulties in solving for the extensive margin of imports in a multi-country model with multiple intermediate inputs and heterogeneous fixed costs of sourcing. Recently, Antràs et al. (2017) have analyzed interdependent market entry in a global sourcing framework by applying a solution mechanism introduced by Jia (2008). We model the interdependent market choices in an export setting and solve the model for J heterogeneous markets across a wide range of parameter values.

Third, our paper adds to the literature of economic integration and the effect of international trade on harmonizing international prices which studies firms' incentives to pay fixed costs to conduct price discrimination (Méjean and Schwellnus, 2009; Anderton et al., 2007; Rogoff, 1996; Goldberg and Knetter, 1997). The strength of our approach is to compare the model outcomes under market integration to the outcomes when markets are perfectly segmented.

We also add to the welfare literature, where Arkolakis et al. (2012) show that for a given model class trade induced welfare gains depend only on the gravity-based elasticity of trade to changes in trade costs as well as the trade shares both before and after the change in trade costs. It is explicitly independent of the endogenous exit and export decisions. We extend this framework by providing a similar expression for a model class for which there are no closed-form solutions. Finally, our work relates to Eaton et al. (2004) and Eaton et al. (2011) who highlight the impact of fixed costs on firm-specific export decisions (see also De Loecker, 2007). Instead, we model fixed costs with a stochastic component.

Structure. The paper is organized as follows. Section 3.2 starts with a brief review of economic integration, while Section 3.3 presents a detailed exposition of the model. Section 3.4 describes the respective equilibrium. Section 3.5 explains the calibration procedure, and Section 3.6 presents the simulation results. Section 3.7 provides sensitivity results, and Section 3.8 concludes.

3.2 Institutional and theoretical background

3.2.1 Causes and consequences of economic integration

Economic integration is defined as an "institutional combination of separate national economies into larger economic blocs or communities" (Robson, 1980, p.1).[5] Indeed, during the last decades, there have been substantial improvements to trading goods, services, and capital across borders. The first milestones towards stronger market integration date back to the period after World War II, where progress particularly relates to technological capabilities including the fields of telephone communication and container transportation. For example, in 1930, a three-minute phone call between New York and London cost 250 US$, while nowadays the same call costs less than 23 US cents. Panel (a) of Figure 3.1 shows the time series of sea freight costs, international calling costs and passenger air transport costs, all between 1930 (normalized to 100) and 2002. For all measures, we observe a sharp decline in the cost index. The technological progress, which has, for example, replaced small ships by gigantic container ships, was also accompanied alongside by trade integration (Donaldson and Hornbeck, 2016).

The first step towards trade integration was taken in 1947 when 23 countries signed the 'General Agreement on Tariffs and Trade' (GATT), which is the founding step for a wide range of actions to abolish a range of customs duties and encourage countries to engage in international trade. Tariffs on industrial products have fallen steeply and now average less than 5% in industrial countries. During the first 25 years after World War II, global trade grew with 8% per year even faster than global economic growth, averaging about 5% during the period. This is only partly reflected by the original agreement, but also linked to later organizations including the 'European Economic Community' (EEC), or the 'Association of Southwest Asian Nations' (ASEAN). Popular measures include removing tariffs, quotas, and other tax types, and simplifying customs procedures, enforcing anti-discrimination laws and disclosure of member countries. Part of these measures is, however, not linked to global institutions or unions but on a more granular level to bilateral agreements.

Overall, Balassa (1961) distinguishes between the following five degrees of integration — coined as five stages of integration by Balassa (1975): 'free trade agreements' establishing free trade within a restricted group of member countries; 'customs unions', which also agree on a common external tariff towards non-member countries; 'common markets', where besides trade frictions factor mobility of capital and labor is fostered; 'economic unions', which already unify within-country policy rules and finally 'complete economic integration', which combines the previous measures with common policy regulations in monetary and fiscal terms, concentrating power also in supra-national authorities (see also Huwart and Verdier, 2013).

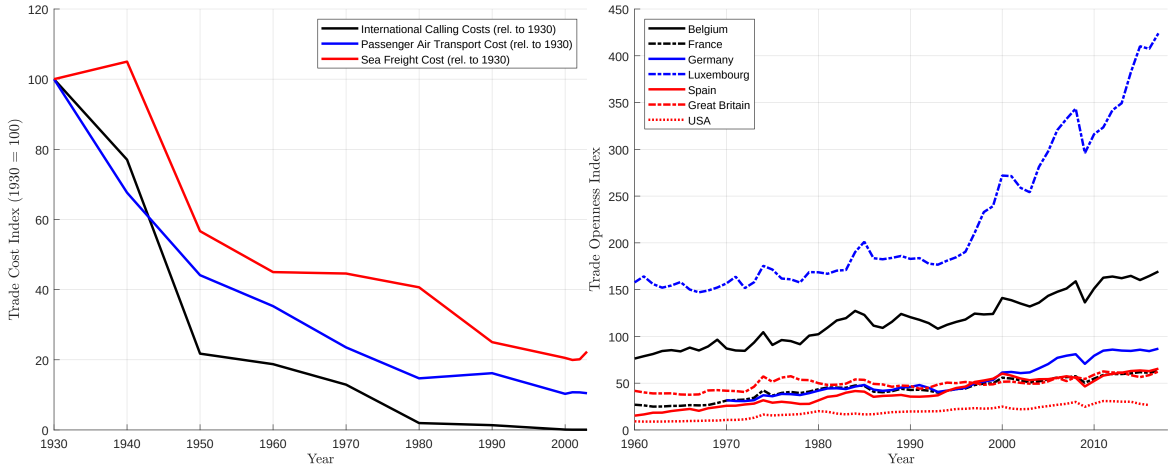
It is well established that market integration leads to substantially increasing trade relations. To pin down patterns in a single number, Panel (b) of Figure 3.1 shows the trade openness index

[5]Concerning economic integration, Balassa (1961) distinguishes between a process and a stage of affairs. While the former describes measures to abolish discrimination potential, the stage of affairs refers to "the absence of forms of discrimination between national economies" (p.1) (see also Sapir, 2011).

— defined as the sum of imports and exports in goods and services relative to the respective country's GDP. The larger a country's openness, the higher is the index. In the period from 1960 to 2018, the index has more than doubled for Luxembourg from 157 to 410, or for Great Britain from 85 to 170. On the other hand, it has remained stable for the United States.[6] For the tariff reductions in the light of the 'North American Free Trade Agreement' (NAFTA), Caliendo and Parro (2015) quantify intra-block trade changes of 118% for Mexico, 11% for Canada, and 41% for the United States. Apart from changing trade patterns, market integration also leads to welfare changes. In the current example, Mexico and the US have gained 1.31% and 0.08%, respectively, whereas Canada suffered a welfare loss of 0.06%.[7]

Figure 3.1: Transportation Costs and Trade Openness

(a) Transportation Costs, 1930−2002 (b) Trade Openness Index



Notes: Panel (a) shows data on the average international freight charges per ton (sea freight cost), the average airline revenue per passenger mile until 2000 spliced to US import air passenger fares (passenger air transport) and the cost of a three-minute call from New York to London (international calling costs), 1930−2003. Source: Economic Outlook, OECD (2007). Panel (b) displays the trade openness index for a subset of OECD countries. The index divides the sum of imports and exports by GDP, 1960−2017. Source: World Development Indicators, World Bank (2017).

Based on these findings, we briefly discuss two possible channels about how economic integration affects the economy. For one, integrating markets lowers real trading costs by abolishing quotas, border checks, and harmonizing different norms and regulations. In addition, market entry costs are reduced by shutting down capital controls (Méjean and Schwellnus, 2009; Anderton et al., 2007). All measures create incentives to engage in international trade to benefit from specialization and intra-industry trade.[8]

A second channel relates to the market allocation efficiency. Deeper market integration rises competition between firms across borders, deteriorating markups and monopoly rents, thus shifting prices down to marginal costs. Closely related, the larger competition also leads to larger varieties of goods which is in particular welfare-enhancing in a monopolistic competition setting. Firms also adopt more advanced technologies, both related to products and processes (Atkeson and Burstein, 2010). Further, consumers find it easier to make price comparisons across borders, leading to an additional competition force besides the previously described rise

[6] In 1960, the average index in the world was 52.48, compared to 97.82 in 2018.

[7] Levchenko and Zhang (2012) find similar heterogeneity in the welfare patterns for the fall of the Soviet Union and the integration of East-Europe's markets. The average gain was 9.23% for East-European countries, while the average welfare gains for West-European markets were 0.16%.

[8] Still, only a fraction of firms serves foreign markets, even in export-oriented sectors. This originates from the selection effect meaning that the productivity of exporting firms is larger than for non-exporting firms (see, e.g., Bernard and Jensen, 1995, 1999, 2004b; Clerides et al., 1998; Eaton et al., 2004).

in product supply. Finally, abolishing (non-)trade barriers and related transaction costs lowers firms' incentives to charge different prices. At this stage, there is clear evidence in favor of larger market integration.[9]

3.2.2 The theory of price integration

The previous section has shown that economic integration lowers trade frictions and improves market efficiency of allocating products to consumers. In combination with additional improvements such as a common currency that eliminates real exchange rate fluctuations, this may create incentives for firms to charge a single price for different markets, satisfying the 'Law of One Price' (LOOP). The LOOP states that in absence of any trade frictions, including transport costs and tariffs, and under conditions of free competition and price flexibility, identical goods purchased in different locations must have identical prices when expressed in a common currency. Firms may comply with single-pricing in the presence of cross-border arbitrage, i.e., when persistent price differences encourage consumers to re-import goods at lower prices. On the intra-national level with different markets, this behavior is best explained by either avoiding menu costs when writing different price lists for different markets, or driven by the company's fear that consumers might choose close substitutes (see DellaVigna and Gentzkow, 2019; Cho and Rust, 2010; McMillan, 2007).

These incentives counteract the 'pricing-to-market' (PTM) mechanism introduced by Krugman (1987).[10] The idea is that the goods producer changes the relative price at which she sells her output abroad and at home in response to changes in international relative costs violating the 'relative purchasing power parity' (relative PPP). Besides the influence of volatile exchange rates, empirical studies of single industries (Goldberg and Verboven, 2005) or varieties of (electronic) goods (Engel and Rogers, 2004) mostly find evidence in favor of pricing-to-market. So far, both pricing schemes have been rationalized using firm-level data, leaving this an unclear matter. In the following, we take the country perspective and review data in the context of the EMU for which the major frictions (e.g., exchange rate fluctuations) have been abolished.

3.2.3 Country-level evidence on price integration

In this section, we review some country-level evidence on price integration. We consider the example of the EMU constituting one of the most deeply integrated markets with 19 member countries and a single currency. The integration process began in 1992 when 12 member countries of the 'European Union' (EU) completed 300 actions determined by the 'Single Market Program' (SMP) of 1986 in favor of removing trade barriers and heterogeneous product standards. There is strong evidence that introducing the euro in 1999 has boosted within-EU trade, 'Foreign Direct Investment' (FDI) and cross-border mergers, all necessary conditions for price integration (Ilzkovitz et al., 2007).

In the following, we use two different versions of price convergence data from Eurostat. For one, we show the variation coefficient of the price level in households' final consumption. Panel (a) of Figure 3.2 displays the patterns for the EU-28 countries (black line), the EU-15 countries (blue line), and the set of EA-19 countries (red line) starting in 1995 until 2018. The results show a decreasing relationship for all groups between 1995 and 2008 showing progress towards integration. From 2008 onward, the index remains stable for the EU-28 and EU-15 countries, while showing even price divergence for the EMU (EA-19) countries.[11]

Second, we show country-specific price level data on the 'Actual Individual Consumption' (AIC) in the period between 1995 and 2018. The index is measured relative to the set of EU-28

[9] Yet, there are attempts to reverse market integration. Most prominently, the UK has voted in favor of leaving the EU, and there is a substantial protest against the 'Transatlantic Trade and Investment Partnership' (TTIP).

[10] Recent applications include Burstein and Gopinath (2014); Bernard et al. (2012); Alessandria and Kaboski (2011); Atkeson and Burstein (2008). Note that the original PTM approach builds on fully independent markets.

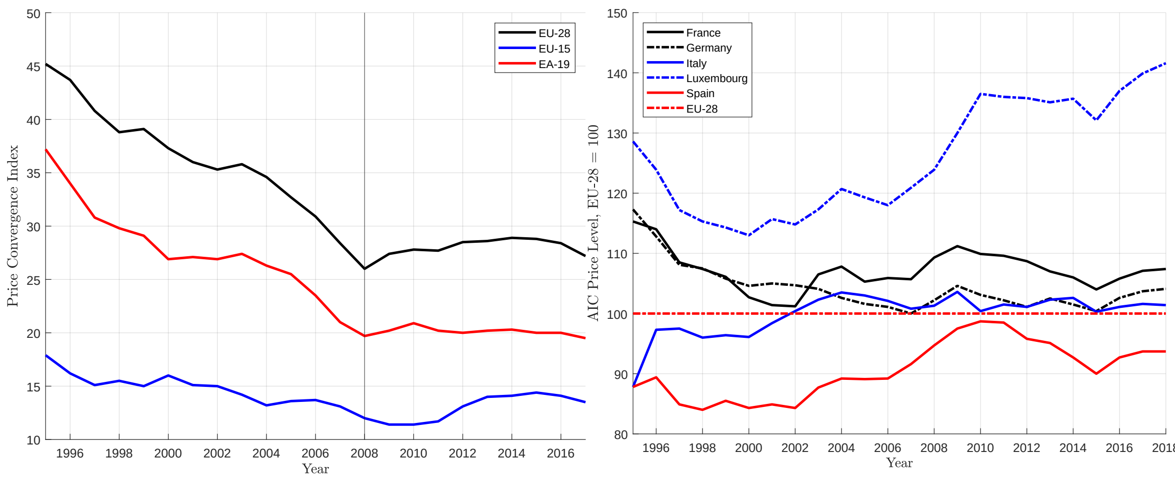
[11] The data are taken from the table 'prc-ppp-conv' and are available at Eurostat (Eurostat, 2019).

countries (normalized to 100).[12] According to Panel (b) of Figure 3.2, there has been convergence until 2001 for countries with lower price levels, e.g., Spain and Italy, as well as for countries with higher price indices, as e.g., Luxembourg and Germany, all relative to the EU-28 index. After 2002, however, volatility increases in Luxembourg, thus showing strongly diverging patterns. The related AIC price level rises to 140 in 2018.[13] From this descriptive evidence, we conclude that even eliminating the real exchange rate risks does not lead to perfect price integration. There are several possible explanations for this:

First and foremost, the required network integration may be achieved at a slower pace than initially intended. Furthermore, there may be inefficiencies related to transport costs (Burstein et al., 2003) and border costs (Engel and Rogers, 1996); or it could be due to price sensitivity with respect to complementary goods (Dvir and Strasser, 2018). Overall, there is mixed evidence of price integration for firm-level data and evidence against price convergence on the country level.

Figure 3.2: Price Convergence in the EMU/EU

(a) Price Convergence, 1995−2018 (b) AIC Price Level, 1995−2018



Notes: Panel (a) displays the variation coefficient of final household consumption expenditure for the EU-28, EU-15, and EA-19 countries, 1995−2018. Panel (b) shows the 'Actual Individual Consumption' (AIC) price index for different countries (EU-28 = 100), 1995−2018. Source: Eurostat (2019).

To investigate the potential consequences of price integration both on firm-specific decisions and on the aggregate variables, such as the equilibrium number of firms or the welfare level, we proceed in two steps. In the first step, we show why the standard heterogeneous firm model is insufficient to model price integration and in the second step, we develop a suitable framework.

3.2.4 A simple way to model price integration

To infer why the standard heterogeneous firm model is inappropriate, consider three countries $\{i, j, k\}$, where country i is the exporter, while the countries j and k are importers. Assume that the two importing markets are located in the same region, while the export market is not. It is

[12] The set of EU-15 countries includes: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden and United Kingdom. The set of EU-28 countries consists of the EU-15 countries including Bulgaria, Croatia, Cyprus, Czechia, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia and Slovenia. The set of EA-19 countries includes Austria, Belgium, Finland, France, Germany, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Greece, Slovenia, Cyprus, Malta, Slovakia, Estonia, Latvia, and Lithuania.

[13] Ilzkovitz et al. (2007) present additional descriptive evidence showing rather diverging patterns in the price index between countries.

interesting to analyze how regional integration between countries j and k, which allows trade at low symmetric trade costs $\tau_{jk} = \tau_{kj}$, affects the behavior of firm ϕ in exporting from location i to both consumers in j and k. Assuming a standard problem of an exporter ϕ in country i, the exporter maximizes the following profit function:[14]

$$\Pi_i(\phi) = \pi_{ij}(\phi) + \pi_{ik}(\phi) \tag{7}$$

Using a usual market segmentation framework with heterogeneous firms and monopolistic competition (Bernard et al., 2007a), the profit-maximizing consumer prices are given by:

$$p_{ij}(\phi) = \frac{\sigma}{\sigma - 1}\frac{w_i\tau_{ij}}{\phi} \quad \text{and} \quad p_{ik}(\phi) = \frac{\sigma}{\sigma - 1}\frac{w_i\tau_{ik}}{\phi} \tag{8}$$

Usually, against this background, there is the no-arbitrage condition that $\tau_{ij} \leq \tau_{ik}\tau_{kj}$, implying that the following equation must hold:

$$p_{ij}(\phi) \leq p_{ik}(\phi)\tau_{kj} \tag{9}$$

Assuming complete market integration between countries k and j, the trade costs τ_{kj} converge to one, so that in the limit the following condition must be satisfied:

$$p_{ij}(\phi) = p_{ik}(\phi) = p_i(\phi) \tag{10}$$

Perfect price integration can only occur if the bilateral trade costs are equal to one, and any friction related to cross-border trade is removed. Given empirical evidence on the persistence of trade frictions (Anderson and van Wincoop, 2004), we suggest a model setup that combines integrated markets and variable (iceberg) trade costs in a single-price setting. The strength of this approach is twofold: first, we have a suitable framework to compare the outcomes for integrated markets to those under segmentation, both for firms and the aggregate economy.

Besides, our model setup with a single-pricing mechanism reflects a methodological contribution by itself. We explicitly model interdependent market entry and extend the solution method to an arbitrary number of markets by making the fixed costs stochastic. This makes our model class applicable to various settings (e.g., an interdependent innovation decision). The next section presents a detailed model exposition.

3.3 A model framework with integrated markets

We consider an economy with J markets (indexed by i, j), each with L_i immobile workers supplying their labor inelastically. Heterogeneous firms produce distinct varieties of a differentiated good ω. The production structure is of monopolistic competition type with increasing returns to scale.

3.3.1 Preferences and demand

Households derive their utility from the consumption of a differentiated good according to standard 'Constant Elasticity of Substitution' (CES) preferences. They maximize their utility subject to the budget constraint, i.e.,

$$\max_{\{q_{ij}\}_{i=1}^{J}} U_j = \left(\sum_{i \in J} \int_{\Omega_{ij}} q_{ij}(\omega)^{\frac{\sigma-1}{\sigma}} d\omega \right)^{\frac{\sigma}{\sigma-1}} \quad \text{subject to} \sum_{i \in J} \int_{\Omega_{ij}} p_{ij}(\omega) q_{ij}(\omega) d\omega = w_j L_j, \tag{11}$$

[14] Without loss of generality, we exclude local market profits.

where $q_{ij}(\omega)$ denotes the consumption level of variety ω produced in country i and consumed in country j. Ω_{ij} is the set of available goods and $\sigma > 1$ describes the elasticity of substitution. Maximizing equation (11) yields the optimal demand for variety ω

$$q_{ij}(\omega) = \frac{p_{ij}(\omega)^{-\sigma}}{P_j^{1-\sigma}} L_j w_j, \tag{12}$$

where p_{ij} is the consumer price, w_j denotes the wage rate and P_j is the price index in country j. It is given by

$$P_j = \left(\sum_{i \in J} \int_{\Omega_{ij}} p_{ij}(\omega)^{1-\sigma} d\omega \right)^{\frac{1}{1-\sigma}} \tag{13}$$

and denotes the income required for a single unit of utility (see Dixit and Stiglitz, 1977).

3.3.2 Technology and profits

In every country i, there is a mass of firms, N_i, which produce a final good under a monopolistic competition market structure with free entry into the industry. Serving a market requires some fixed labor investment, f_{ij} and thus, the downward-sloping average costs imply increasing returns to scale at the firm level such that every variety is produced in equilibrium by one firm only.

Productivity. Firms need to pay entry costs equal to f_i^e units of labor in country i to learn their productivity ϕ – which we use to identify firms. In line with Melitz (2003), the productivity ϕ is drawn from a country-specific (Pareto) distribution $\phi \sim g(\phi)$, with location parameter b, shape parameter β and support in $[\underline{\phi}, \infty)$. Goods can be traded across markets subject to symmetric iceberg trade costs $\tau_{ij} \geq 1$, implying that τ_{ij} units of the good have to be shipped for one unit to arrive at the place of consumption.

In scenarios with a deterministic notion of market-specific fixed costs, the choice to serve the export market j is binary, i.e., either a firm exports or it does not, and depends on the condition that bilateral profits are non-negative. For a larger number of markets, this involves a combinatoric problem with 2^J choices, where J denotes the number of destination countries. For a setting with integrated markets, the optimal price level is a function of the export decision in all markets and thus unfeasible to optimize in the presence of the resulting functional discontinuity.

To overcome this obstacle, we take advantage of a stochastic notion of fixed costs, assuming that each firm experiences market-specific shocks $\epsilon_{ij} \in [1; \infty)$ which affect the payable level of fixed costs. Particularly, we assume fixed costs paid in terms of labor, $w_i f_{ij}/\epsilon_{ij}$, where the stochastic component of the fixed costs ϵ_{ij} is such that

$$\frac{1}{\epsilon_{ij}} \in (0, 1] \tag{14}$$

The firms' objective is to maximize their expected profits by setting an optimal price for all markets subject to stochastic fixed costs. Our framework makes the probability of serving a market a continuous function. Furthermore, the integrated market setting makes each firm's pricing decision a function of the aggregate profit function across all destination markets. Formally,

$$\Pi_i(\phi, \epsilon_{ij}) = \sum_j \mathbf{I}_{ij}(\phi) \left(V_{ij}(\phi) w_i f_{ij} - \frac{1}{\epsilon_{ij}} w_i f_{ij} \right), \tag{15}$$

where $\mathbf{I}_{ij}(\phi)$ denotes the probability for firm ϕ producing in market i to serve market j. To streamline notation, we use $p_{i(j)}$ to unify pricing for integrated markets and segmented markets.

Later, we explicitly consider $p_i(\phi)$ for integration and $p_{ij}(\phi)$ for segmentation. Also, we define,

$$V_{ij}(\phi) \equiv \frac{\left(p_{i(j)}(\phi)^{1-\sigma} - p_{i(j)}(\phi)^{-\sigma}\frac{w_i\tau_{ij}}{\phi}\right) w_j L_j P_j^{\sigma-1}}{w_i f_{ij}}. \tag{16}$$

To set profit-maximizing prices under uncertainty, the firm needs information about the shock's distribution. For simplicity, we assume a Pareto distribution $\epsilon_{ij} \sim \text{Pareto}(a, \alpha)$ such that both the cumulative distribution function and the density function are given by, respectively

$$f(\epsilon_{ij}) = \frac{\alpha a^\alpha}{\epsilon_{ij}^{\alpha+1}} \qquad \text{and} \qquad F(\epsilon_{ij}) = 1 - \left(\frac{a}{\epsilon_{ij}}\right)^\alpha. \tag{17}$$

The sufficient condition for firm ϕ to serve market j is to make non-negative profits, $\pi_{ij}(\phi) \geq 0$. Expressed in terms of the stochastic cost component, this implies

$$\epsilon_{ij} \geq \frac{1}{V_{ij}(\phi)}. \tag{18}$$

It leaves the respective stochastic component as a cutoff depending on the productivity realization, ϕ. Each firm thus maximizes its expected profits. We can now approximate the probability by evaluating the cumulative distribution function at $V_{ij}(\phi)$ which delivers the following expression for the export probability:

$$\mathbf{I}_{ij}(\phi) \equiv \Pr(\epsilon_{ij} \geq \epsilon_{ij}^*) = a^\alpha V_{ij}(\phi)^\alpha. \tag{19}$$

Each firm earns non-negative profits if the realization of ϵ_{ij} exceeds the lower bound $1/V_{ij}(\phi)$. In addition, $\mathbf{I}_{ij}(\phi)$ is a function of $V_{ij}(\phi)$ and hence depends on prices as a function of marginal costs. The term $\mathbf{I}_{ij}(\phi)$ can also be interpreted as the share of firms with productivity ϕ producing in market i and serving market j. This interpretation follows as a result of the law of large numbers.

Expected aggregate profits. The impact of integrated markets on firm-specific choices is reflected by the impact of the profit-maximizing price on the probability for a country i firm to enter market j. Collecting the above insights, we can formulate expected profits conditional on exporting (see Appendix 3.A for details) as

$$\mathbb{E}_\epsilon(\Pi_i(\phi)) = \sum_j \left(\frac{1}{\alpha+1}\right) a^\alpha V_{ij}(\phi)^{\alpha+1} w_i f_{ij}, \tag{20}$$

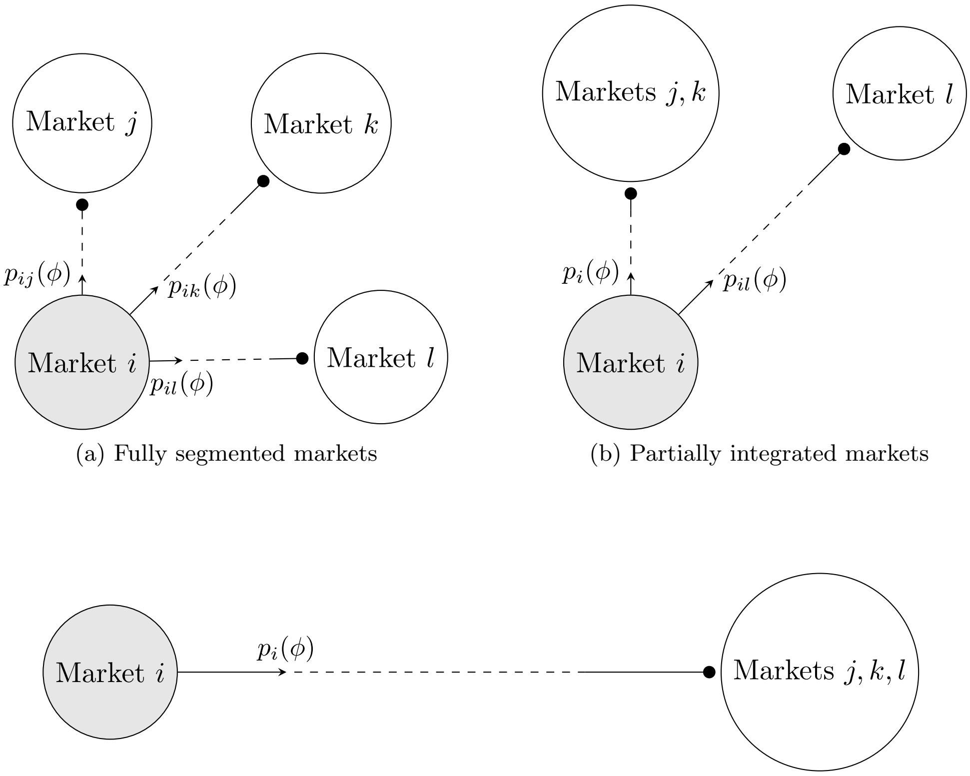
where we use V_{ij} instead of $V_{ij}(\phi)$ from now on for the sake of brevity. Each firm optimally sets a price for all markets to maximize this objective function.

3.4 Equilibrium for integrated and segmented markets

The strength of our model is to nest integrated and segmented markets in a single framework. Figure 3.3 presents a schematic overview. Besides the two edge knife cases of either full market interdependence (see Panel (a)), or perfect segmentation (see Panel (c)), our model also captures an intermediate scenario, where a set of K markets is integrated and the remaining J–K markets are segmented, allowing pricing-to-market (PTM, see Panel (b)). Formally,

$$\mathbb{E}_\epsilon[\Pi_i(\phi)] = \left\{\sum_{j=1}^{K} \frac{1}{\alpha+1}\mathbf{I}_{ij}(p_i)V_{ij}(p_i)w_i f_{ij}\right\} + \left\{\sum_{j=K+1}^{J} \frac{1}{\alpha+1}\mathbf{I}_{ij}(p_{ij})V_{ij}(p_{ij})w_i f_{ij}\right\} \tag{21}$$

Figure 3.3: Schematic Overview of Market Integration



(a) Fully segmented markets

(b) Partially integrated markets

(c) Fully integrated markets

Notes: This figure shows the degree of integration. Panel (a) shows full segmentation (pricing-to-market). Panel (b) displays partially integrated markets. Panel (c) shows integrated markets (single-pricing).

The optimization problem is flexibly solved for the respective setting. We proceed by characterizing the optimal price-setting rule for both the interdependent markets and the markets for which the price is set independently. For the markets in which prices are set interdependently, it follows that each firm ϕ sets one common price $p_{ij} = p_i \ \forall j$ for a set of K destination markets. The optimality condition based on equation (20) is given by

$$\frac{\partial \mathbb{E}_\epsilon(\Pi_i(\phi))}{\partial p_i(\phi)} = \sum_{j=1}^{K} a^\alpha V_{ij}^\alpha V_{ij}' w_i f_{ij} = 0, \tag{22}$$

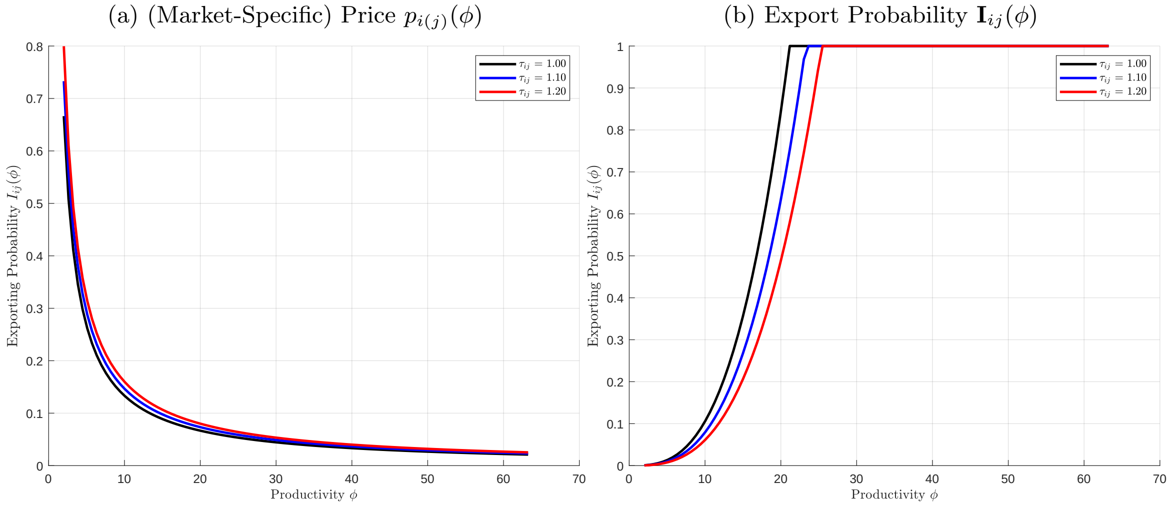
where $V_{ij}' \equiv \partial V_{ij}/\partial p_i$ and the group of interdependent markets is restricted to $K \leq J$. This condition implicitly defines the profit-maximizing price across markets. Importantly, equation (22) includes information from all markets, in particular, market entry probabilities and potential profits.[15] For each of the remaining $J - K$ markets, firms can perfectly price discriminate, which leads to the well-known pricing-to-market equation:

$$p_{ij}(\phi) = \frac{\sigma}{\sigma - 1} \frac{w_i \tau_{ij}}{\phi} \tag{23}$$

To summarize, price integration means that the pricing decision becomes a function of all export probabilities. An immediate implication is the presence of variable markups because prices over marginal costs are no longer constant, given the heterogeneity in marginal costs. The mechanism also modifies the firms' rationale towards serving foreign markets. In the standard model of

[15]For complete symmetry including $\tau_{ij} = 1 \ \forall i, j \in J$, the price-setting under segmented markets and interdependent markets is identical with interpreting multiple markets in terms of one large market.

Figure 3.4: Pricing and Export Exposure



Notes: Panel (a) displays the price $p_{i(j)}$ for different trade cost levels τ_{ij} as a function of productivity ϕ. Panel (b) displays the export exposure $\mathbf{I}_{ij}$ for different trade cost levels τ_{ij} as a function of productivity ϕ.

heterogeneous firms, a firm exports if and only if foreign sales compensate for the fixed market entry costs. In our setting, profits depend on the single-pricing and are hence a function of the profits generated in all other destination markets.

Further, our model adds interesting insights towards pricing. Similar to the canonical model, consumers benefit from lower pricing in terms of real income and welfare. Also, more productive firms charge lower prices than low-productivity firms. On the other hand, market integration makes the charged price a weighted (by market size and trade costs) average of the prices charged under perfect market segmentation.[16] Panel (a) of Figure 3.4 illustrates the decreasing pricing pattern as a function of productivity ϕ for both segmented and integrated markets. It is also obvious that for a given firm ϕ, the charged price is an increasing function of bilateral trade costs τ_{ij}.

The stochastic nature of market-specific fixed costs alters the notion of an exporting firm. While the export choice is typically binary, firm ϕ faces an export probability ($\mathbf{I}_{ij}$) in our setting. This probability depends on the realization ϵ_{ij} allowing us to interpret this probability — as a result of the law of large numbers — as the share of firms ϕ serving the market. To illustrate the link between the share of exporting firms and ϕ, we impose the zero-profit cutoff condition by noting that $\pi_{ij}(\phi^*_{ij}) = 0$. It follows that

$$V_{ij} w_i f_{ij} = \frac{1}{\epsilon^*_{ij}} w_i f_{ij} \iff \epsilon^*_{ij} = V_{ij}^{-1}. \tag{24}$$

Importantly, both productivity (ϕ) and the stochastic component of the fixed costs (ϵ_{ij}) jointly determine market j's profits, thus, defining the marginal firms.[17] To be more precise, there will be a share of firms drawing the lowest possible realization of ϵ_{ij}, allowing also low-productivity to serve the market. Hence, the productivity cutoff is not fixed but follows a distribution with lower bound, $\phi^*_{ij} = \underline{\phi}_{ij}$. Combining equation (24) and equation (16), the productivity cutoff in

[16]Figure 3.8 in Appendix 3.B shows the patterns of the aggregate expected profits as a function of trade costs. Figure 3.9 illustrates the integrated market pricing, where the optimal price is larger than the segmented price in the domestic market but smaller than the segmented prices in different export markets.

[17]Note that upon realizing ϵ_{ij}, the firm cannot readjust the chosen price. Otherwise, the market entry choice would turn binary, leading to a discontinuous objective function.

terms of the stochastic fixed costs is given by

$$\epsilon_{ij}^*(\phi) = \left[\frac{\left(p_{i(j)}(\phi_{ij}^*)^{1-\sigma} - p_{i(j)}(\phi_{ij}^*)^{-\sigma} \frac{w_i \tau_{ij}}{\phi_{ij}^*} \right) w_j L_j P_j^{\sigma-1}}{w_i f_{ij}} \right]^{-1}. \tag{25}$$

Panel (b) of Figure 3.4 shows that the export probability is increasing in the productivity level (ϕ) and holding productivity constant, is a decreasing function of the bilateral trade costs (τ_{ij}). This holds for both segmented and integrated markets. We can implicitly determine a cutoff value ϕ^{**}, above which a firm of productivity $\phi > \phi^{**}$ exports with certainty by noting that

$$\mathbf{I}_{ij}(\phi^{**}) \stackrel{!}{=} 1 \iff V_{ij}(\phi^{**}) \geq \frac{1}{a}. \tag{26}$$

We infer that this threshold is a decreasing function of the bilateral trade costs (τ_{ij}) but increasing in country j's income level (Y_j). To close and solve the model in general equilibrium, we determine wages w_i and the number of entering firms N_i by imposing free entry and the labor market clearing condition. Free entry requires that firms enter the market until the ex-ante expected profits equal participation costs ('lottery costs'). Formally,

$$\mathbb{E}_\epsilon(\Pi_i) = \left(\frac{1}{\alpha+1} \right) \sum_j \int_\Phi \mathbf{I}_{ij}(\phi) V_{ij} w_i f_{ij} f(\phi) d\phi = f_i^e w_i. \tag{27}$$

Labor markets. In equilibrium, country i's labor supply equals its labor demand. Firms hire workers to cover participation costs ('lottery costs'), market-specific fixed costs ('fixed export costs'), and to produce goods. The resulting market clearing condition can be stated as

$$L_i = N_i f_i^e + N_i \sum_j \int_\Phi \mathbf{I}_{ij}(\phi) \frac{p_{i(j)}(\phi)^{-\sigma} \tau_{ij}}{\phi} Y_j P_j^{\sigma-1} f(\phi) d\phi + N_i \sum_j \int_\Phi \mathbf{I}_{ij}(\phi) f_{ij} f(\phi) d\phi. \tag{28}$$

This relationship allows determining the number of firms in country i by noting that

$$N_i = \frac{L_i}{(1+\alpha) f_i^e + \sum_j \int_\Phi \mathbf{I}_{ij}(\phi) p_{i(j)}(\phi)^{-\sigma} \frac{\tau_{ij}}{\phi} Y_j P_j^{\sigma-1} f(\phi) d\phi}. \tag{29}$$

Importantly, the number of domestic firms N_i is proportional to the respective labor force L_i, inversely related to the lottery costs (f_i^e), the income level (Y_j), the export probability ($\mathbf{I}_{ij}$) and the bilateral trade costs (τ_{ij}). Also, it is increasing in the pricing ($p_{i(j)}$) and the productivity level (ϕ). To close the model, we could alternatively use the requirement that income equals revenues, which is given by

$$\frac{\alpha}{\alpha+1} \sum_j \int_\Phi \mathbf{I}_{ij}(\phi) V_{ij} w_i f_{ij} f(\phi) d\phi = \sum_j \int_\Phi \mathbf{I}_{ij}(\phi) w_i f_{ij} f(\phi) d\phi. \tag{30}$$

Upon the choice of the numéraire, $w_i = 1$, the previous equations solve the model.

Aggregate trade flows. To determine the impact of trade liberalization on the aggregate economy and the induced trade flows captured by the expenditure share λ_{ij}, we denote the total value of country j's imports from country i as a function of the number of firms N_i in the home country and the aggregate price index P_j of the destination country. Formally,

$$X_{ij}(\phi) = Y_j P_j^{\sigma-1} N_i \int_{\underline{\phi}_i}^{\infty} \mathbf{I}_{ij}(\phi) p_{i(j)}(\phi)^{1-\sigma} f(\phi) d\phi, \tag{31}$$

where $Y_j = \sum_i X_{ij}$ denotes country j's total expenditures. This relationship reflects the gravity equation.[18] Following Costinot and Rodríguez-Clare (2014), the expenditure share of goods imported from exporter i is given by

$$\lambda_{ij} = \frac{X_{ij}}{X_j} = \frac{N_i \int_{\Phi} \mathbf{I}_{ij}(\phi) p_{i(j)}(\phi)^{1-\sigma} f(\phi) d\phi}{P_j^{1-\sigma}}, \tag{32}$$

where $X_j = \sum_k X_{kj}$ denotes the aggregate expenditures by country j and the taste of variety price index is a function of the number of firms N_k, the export exposure $\mathbf{I}_{ij}$ and the price $p_{k(j)}$,

$$P_j = \left[\sum_k N_k \int_{\Phi} \mathbf{I}_{kj}(\phi) p_{k(j)}(\phi)^{1-\sigma} f(\phi) d\phi \right]^{1/(1-\sigma)}. \tag{33}$$

The CES price index is increasing in pricing, decreasing in N_k, and as a new ingredient, in the market probability $\mathbf{I}_{ij}$. In equilibrium, the budget constraint and the market clearing condition require that expenditure equals income, $Y_i = X_i$, and that $Y_i = \sum_j X_{ij}$ for all countries, respectively. This condition states that all income is derived from goods exports.

Goods market. In equilibrium, the income derived from labor, $w_i L_i$, must be equal to the expenditures on the goods purchased from each location by market i. The expenditure level is a function of the market-specific expenditure share, λ_{ij}. Combining these insights, we obtain

$$w_i L_i = \sum_{j \in J} \lambda_{ij} w_j L_j, \tag{34}$$

where λ_{ij} denotes the trade share of goods exported from country i to j. One crucial quantity to assess between interdependent markets and segmented markets is the average productivity of firms within markets.

Equilibrium. The equilibrium in this model consists of a vector with five endogenous variables $\{p_{i(j)}, P_j, \lambda_{ij}, w_i, N_i\}_{j=1}^{J}$ that solve the following equations: Upon the choice of the numéraire, $w_i = 1$, the equation on optimal pricing (22), the aggregate price level P_j (33), the gravity equation (32), the labor market clearing (29), and goods market clearing (34) solve the model. We update the wage w_j by using the goods market clearing condition.

3.5 Model calibration

Quantifying the model requires a wide range of parameter values and exogenous variables. We calibrate a stylized version of the model from the perspective of firm ϕ, which produces in market i. In the baseline scenario, we consider $J = 4$ markets to appropriately capture market integration but have an eye on computational time. The substitution elasticity between different goods in the CES utility function, $\sigma = 4$, follows the choice by Broda and Weinstein (2004).

We further set market entry costs (also termed fixed trade costs) for all non-domestic export markets to $f_{ij} = 1e^3$ and choose $f_{ii} = 1e^1$ for all domestic markets. The respective choice follows closely the argument by Arkolakis (2010), which requires sufficiently large market entry costs to account for partial market entry. Intuitively, we choose larger entry costs for the foreign

[18] See Costinot and Rodríguez-Clare (2014), Chaney (2008) and Anderson (1979) for reference.

markets ($j \neq i$) compared to the home market. In particular, there are more complicated legal requirements and additional barriers (e.g., languages) involved, driving up market entry costs relative to the domestic market. Nevertheless, we provide evidence that both the qualitative firm patterns and the welfare gains of trade liberalization are robust to the choice of fixed costs.

We follow Nigai (2017) and normalize lottery participation costs to $f_i^e = 1$ unit(s) of labor. Each firm pays this fee upfront in terms of labor measured by the wage level to learn its productivity level ϕ. It has no severe effect on the actual exporting decision, making it of sunk-cost type. Our normalization ensures positive but sufficiently low lottery costs relative to market entry costs. In the next step, we set parameter values for the Pareto distributions of both the stochastic fixed costs and the realizations of the productivity levels.

Table 3.1: Model Calibration

	Parameter	Value
σ	Substitution elasticity	4
f_{ij}, f_{ii}	Market entry costs	$1e^3$, $1e^1$
f_i^e	Participation costs	1
a	Location parameter fixed costs	10
b	Location parameter productivity	2
α	Shape parameter fixed costs	3
β	Shape parameter productivity	3
L_i	Labor force	100

Notes: This table displays the full set of parameters.

For both distributions, we need to specify a set of location parameters (a, b), as well as shape parameters (α, β). To keep matters simple and avoid outliers, we set for the productivity distribution the respective parameter values to $b = 2$ and $\beta = 3$. Given that large realizations of stochastic fixed costs also enable low-productivity firms to export, we set the location parameter to $a = 10$ and $\alpha = 3$. The respective choice for the shape parameters α and β ensure finite second moments but have no impact on the observed patterns.[19]

Finally, we assume an aggregate labor force by setting $L = 400$. For the baseline scenario with $J = 4$ markets, this leads to $L_i = 100$. The last section extends the analysis to non-symmetric markets in terms of the labor size and trade costs. Table 3.1 displays the full set of parameter values and exogenous variables.

3.6 Quantifying the effect of integrated markets

In this section, we use the model to evaluate how single-pricing affects heterogeneous firms. We first contrast firm-specific patterns by asking how this setting affects firms in their (i) pricing decision, (ii) their exporting probability, and (iii) their expected profits, all relative to pricing-to-market. Further, we evaluate the differences in the equilibrium number of firms between the two settings.

Admittedly, this yields no insights on the aggregate perspective and induced welfare gains. Therefore, we use a second exercise to quantify the welfare gains of trade liberalization where the bilateral trade costs decline. A third exercise evaluates the welfare gains of trade liberalization when assuming imperfect price integration, i.e., the single-pricing is binding only for a subset of markets, K, where $K \subseteq J$.

[19] To define moments, the shape parameters must be larger or equal to $(\alpha, \beta) = (3{,}3)$. Otherwise, the variance is not defined.

3.6.1 The impact of price integration on firms

In this section, we evaluate how variable trade costs τ_{ij} affect firms under integrated and segmented markets. For a reliable comparison of firms in their optimal (i) pricing decision, (ii) exporting probabilities, and (iii) expected profits between the integrated and segmented settings, we determine the respective ratio between the two settings for a case with trade frictions as well as an ideal world with no frictions, i.e., $\tau_{ij} = 1$.

Effects on pricing. First and foremost, we draw the attention to the pricing differences and determine $p_i(\phi)/p_{ij}(\phi)$, which is a function of productivity and the trade cost level. Panel (a) of Figure 3.5 displays the results. Ratios less or equal to one indicate that the equilibrium price for integrated markets is less or equal to the market-specific prices. This pattern holds across the entire productivity distribution and confirms the intuition that the single-pricing is a weighted average of all destination prices. Conditional on exporting, a low-productivity firm charges a price up to 20% less, relative to the price charged under segmentation. The observed pattern relates instantly to heterogeneity in the bilateral trade costs.

A second finding is an inverse relationship between the pricing gap and the productivity level. It implies that firms at the upper end of the productivity distribution charge a price that is independent of the setting, while firms at the lower end of the distribution differ across the settings. The explanation is that an identical difference for both low- and high-productivity firms translates into a smaller percentage difference for high productive firms, only as a result of the level effect. We learn from this exercise that firms of different productivity are also affected differently by the pricing rule.

In a final step, we evaluate the differences for variable trade cost levels and observe that larger trade cost levels translate into a larger pricing gap, holding constant firm productivity ϕ. Trivially, if all markets are perfectly symmetric including the home market, the outcomes for both scenarios are identical. The results also show that our model nests the standard Melitz (2003) representation of price integration as a special case. To be more precise, we set trade costs uniquely to one, which gives an identical pricing choice for all productivity levels. Note that the remaining differences for low-productivity firms result from numerical deviations and some fixed costs heterogeneity because of $f_{ii} < f_{ij}$. The impact is stronger for integrated markets.

Effects on export probabilities. The stochastic fixed costs ensure that each firm can potentially serve foreign markets, given a sufficiently large realization of ϵ_{ij}.[20] In this regard, our model deviates from Melitz (2003)'s canonical model where the export decision is binary, and dependent on a fixed productivity cutoff ϕ^*. We explore the relationship

$$\eta = \frac{\mathbf{I}_{ij}^{int}(\phi)}{\mathbf{I}_{ij}^{seg}(\phi)} = \frac{\left(p_i(\phi)^{1-\sigma} - p_i(\phi)^{-\sigma}\dfrac{w_i\tau_{ij}}{\phi}\right) w_{j,int}P_{j,int}^{\sigma-1}}{\left(p_{ij}(\phi)^{1-\sigma} - p_{ij}(\phi)^{-\sigma}\dfrac{w_i\tau_{ij}}{\phi}\right) w_{j,seg}P_{j,seg}^{\sigma-1}}, \tag{35}$$

where $p_i(\phi) < p_{ij}(\phi)$ for all productivity levels. Panel (b) of Figure 3.5 shows the results. First, the ratio is either less than or equal to one, implying that the likelihood of serving a segmented market j is larger than serving an integrated market. This effect is at odds with the inverse relationship between pricing and the export probability, i.e., the fraction of exporting firms are decreasing in the price level. The effect of having a larger export likelihood for the segmented market despite a larger price is driven by the aggregate price index P_j, which is according to equation (33) a complex interaction between the number of firms N_k, the export exposure $\mathbf{I}_{kj}$

[20] For a graphical representation of bilateral profits as a function of productivity ϕ and stochastic fixed costs ϵ_{ij}, see Figure 3.10 in Appendix 3.B.

and the pricing p_k. Our simulations show that

$$P_{j,int} > P_{j,seg}, \tag{36}$$

given that the large trade costs prevent foreign firms from exporting. Consumers in the importing region j thus have merely access to varieties produced in market j, rather than to cheaper products from market i. Despite, firms producing in market i find it less profitable to export, leading to a larger CES price index rise compared to segmented markets. The observed pattern is increasing in the trade cost level. As such, for $\tau_{ij} = 1.20$, price integration lowers the market entry probability for low-productivity firms by up to 40% compared to segmented markets.

In addition, the ratio of export exposures is an increasing function of productivity. For the most productive firms, the export probabilities are bounded by one, which implies that they export in all markets irrespective of the fixed costs. This follows from the expected revenues generated by the respective firm and the firm's decision to export only if the profits are non-negative. The choice of $f_{ii} = 1e^1$ restricts the extensive margin in the home market, enabling (almost) every firm to serve its own market.

Finally, large trade cost levels deteriorate less productive firms' performance under integrated markets. Following the negative relationship between export exposure and the trade cost level, this decline is stronger for integrated markets because of the reduced flexibility in pricing. For the special case of zero trade costs, i.e., $\tau_{ij} = 1.00$, the export probability is for almost all productivity levels equal to one; a minor exception is the lower end of the productivity distribution for which market entry costs are still too high.

Effects on expected aggregate profits. We further evaluate the expected aggregate profits of firms in market i, $\mathbb{E}_\epsilon [\Pi_i(\phi)]$. Equation (20) shows that the expected profits are a function of wages, market entry costs, and the variable V_{ij}. The preceding paragraph implies that[21]

$$V_{ij}(\phi)^{int} < V_{ij}(\phi)^{seg}, \tag{37}$$

which follows from the lower optimal price and export exposure under integrated markets. As a result, we confirm the finding by Méjean and Schwellnus (2009) that operating profits are always larger for segmented markets, creating incentives for firms to discriminate whenever possible. Panel (c) of Figure 3.5 displays the expected profit ratios.

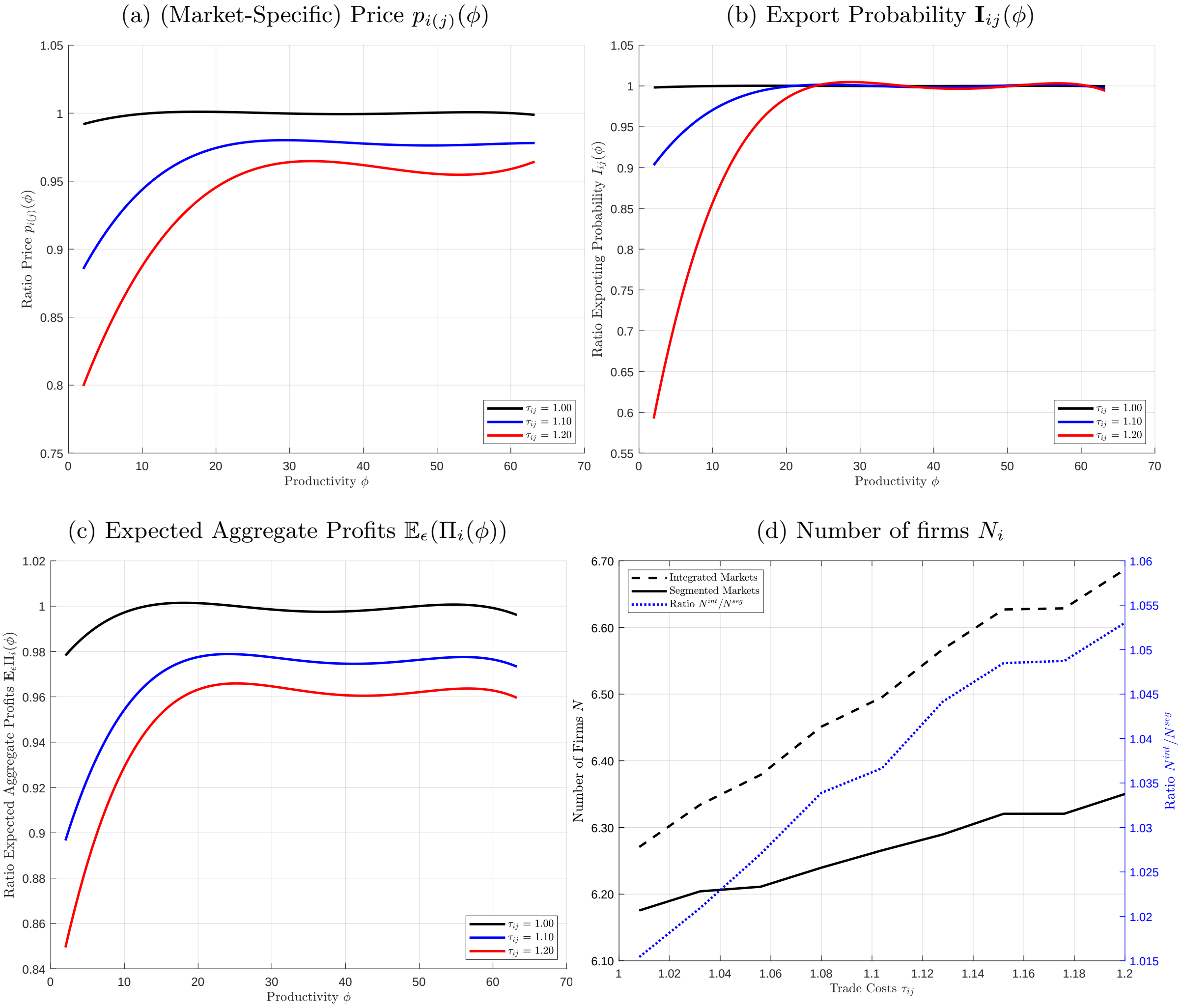
We make two findings. First, the expected profits are larger for segmented markets than for integrated markets. Specifically, for larger trade costs $\tau_{ij} = 1.20$, expected profits in integrated markets are between 84% and 96% — depending on productivity ϕ — of those in segmented markets. Sufficiently productive firms in the latter case can set optimal prices $p_{ij}(\phi)$ and serve all markets. Integration comes at the cost of setting a weighted price, which is too low for some destinations, thus preventing firms from serving these markets. Second, we find that for more productive firms, the expected profit ratio can either be increasing as for the intermediate part of the distribution, or be constant for the high-productivity firms.

The results also allow to establish a decreasing relationship for the level of trade costs. For example, if there are no trade frictions, the expected profits are equal across the two scenarios. On the other hand, for trade frictions of 20%, the ratio declines to 0.85.

Effects on the number of firms. The last part of our qualitative analysis investigates the impact of price integration on the equilibrium number of firms. Panel (d) of Figure 3.5 reveals a positive relationship between the number of firms and the level of trade costs in both scenarios. The intuition follows Melitz (2003) in that larger trade costs make market entry profitable for fewer firms, leading to lower demand for labor supply, and thus, a lower real wage w/P. This positively affects the number of domestic firms N_i, irrespective of the pricing scheme.

[21] To see this, note that $\mathbf{I}_{ij}(\phi) = a^\alpha V_{ij}(\phi)^\alpha$.

Figure 3.5: Ratios between Integrated and Segmented Markets



Notes: This figure displays the ratio between integrated and segmented markets for different trade cost levels. Panel (a) shows the ratio for pricing. Panel (b) displays the ratio for the export probability. Panel (c) shows the ratio for the expected aggregate profits. Panel (d) shows the ratio and values for the number of firms.

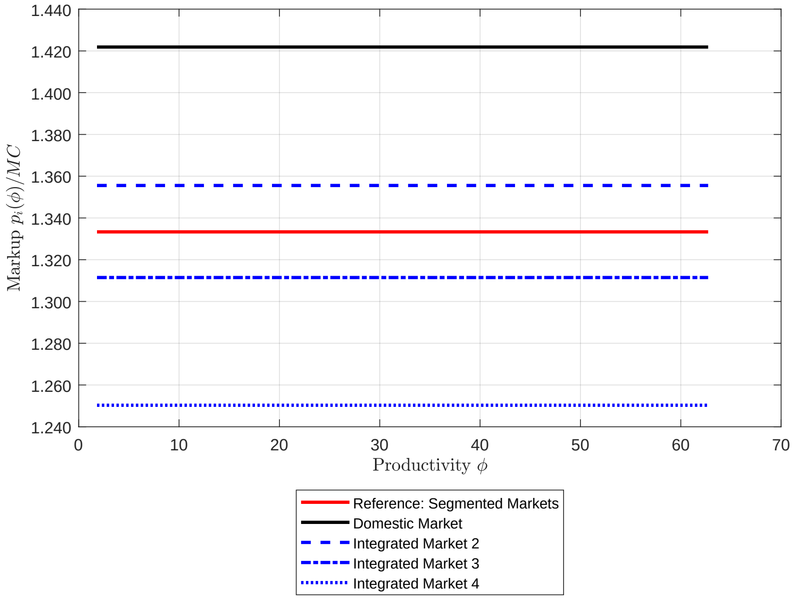
Yet, we observe a sharp increase for integrated markets and a ratio greater than one, indicating a larger competition effect for integrated markets than for segmented markets. To be more precise, large trade costs serve as a market entry constraint for the single-pricing regime. We repeat the exercise holding constant trade cost levels but varying the number of markets J, and the market entry costs f_{ij}, respectively. The patterns remain unchanged, the number of firms is increasing in the trade cost level (see Appendix 3.C for further details).

3.6.2 The role of variable markups

In the canonical version of the heterogeneous firm model, the optimal pricing is a constant markup over marginal costs (Dixit and Stiglitz, 1977). A direct implication of the single-pricing rule is the presence of non-constant markups, given heterogeneous trade costs and market-specific marginal costs. Variability in the markup implies that firms can improve their market share relative to competitors.

Notably, the marginal cost premium reflects influences other than pro-competitive effects coming from trade reductions. Instead, they are purely driven by the single-pricing rule, thus

Figure 3.6: Variable Markups



Notes: This figure shows the markups for heterogeneous trade cost levels τ_{ij} between the exporter i and different importers j. The red line reflects the reference point with segmented markets and constant markups.

allowing our setting to constitute an intermediate case between the demand-driven variable (endogenous) markups (Melitz and Ottaviano, 2008), and the constant markup setting under pricing-to-market (Melitz, 2003; Krugman, 1980). To explore the markups in greater detail, we evaluate prices over marginal costs

$$\rho_{ij}(\phi) = \frac{p_i(\phi)\phi}{w_i \tau_{ij}}. \tag{38}$$

It is obvious that the destination-specific markup is an increasing function of pricing and productivity but decreasing in the wage level and trade costs. The markups are in Figure 3.6.[22]

For all markets, exporter i satisfies the sufficient condition for exporting, i.e., $\rho_{ij} > 1$.[23] Further, markups are market-specific and inversely related to the bilateral trade costs. The largest markup is observed for the domestic market (solid black line), followed by the export market with the lowest trade costs (dashed blue line). The explanation is that the single-pricing results in the relationship $p_i > p_{ii}$, i.e., the weighted price is larger than the domestic price, p_{ii}.

Simultaneously, the single-pricing rule can make it unprofitable for low-productivity firms to serve market j when the markup is low. Note that for all (i, j), ρ_{ij} is constant across the entire productivity distribution, constituting an intermediate case between consumer-specific markups and constant markups. We explore the implications of non-constant markups in the context of trade liberalization in the next section.

3.6.3 Quantification of the welfare gains from trade liberalization

With a clear understanding of the channels, we turn to quantify the welfare gains for integrated markets and segmented markets. We consider an exogenous iceberg trade cost change from τ_{ij} to τ'_{ij}, where $\tau'_{ij} < \tau_{ij}$. The welfare level of a representative consumer in country i corresponds

[22] In this specific exercise, we have assumed heterogeneous trade costs by setting $\tau_{12} = \tau_{21} = 1.20$, $\tau_{13} = \tau_{31} = 1.22$ and $\tau_{14} = \tau_{41} = 1.24$, i.e., we have interpreted markets as unequally distant.

[23] Values $\rho_{ij} > 1$ indicate that firms make positive profits and serve the market ('conditional on exporting') because prices are larger than marginal costs.

to her real wage w_i/P_i, which can be written as

$$\Delta\text{Welfare} = 100\% \times \left[\ln\left(\frac{w_j'}{w_j}\right) - \ln\left(\frac{P_j'}{P_j}\right)\right], \tag{39}$$

where the composite price index is given by $P_j = \sum_k N_k \int_\Phi \mathbf{I}_{kj}(\phi) p_k(\phi)^{1-\sigma} f(\phi) d\phi$.

The formal relationship shows that welfare is increasing in the (sum of the) number of firms serving market j, $\sum_k N_k$ since a larger number of firms relates to a larger variety of goods. This finding follows the pattern by Melitz (2003) and Krugman (1980) with representative firms but neither stochastic fixed costs nor integrated markets.

Second, welfare is decreasing in the price, $p_{k(j)}(\phi)$ because higher prices lower the quantity of goods affordable to the representative consumer.

A new feature compared to the standard setting is the heterogeneity in pricing. For integrated markets, the domestic price is larger than under segmented markets, $p_i > p_{ii}$, which affects the number of varieties of exporter i such that $N_i^{int} > N_i^{seg}$ and leads to a higher initial welfare level for segmented markets in line with the relationship in equation (36). A new channel is that welfare is increasing in the probability of a country k to export to country j, since all else equal, a rising exporting probability enlarges the fraction of firms serving the destination market.[24]

We quantify the separate welfare gains, assuming for now that domestic trade has no frictions and that other market-pairs (i, j) face initial bilateral trade costs of 20%.[25] Panel (a) of Table 3.2 shows the estimated welfare changes for the main specification. The welfare gains for integrated

Table 3.2: Welfare Gains of Trade Liberalization

	(a) Welfare changes: $\Delta W = 100[(W_{\tau'}/W_\tau) - 1]\%$				
	$\lvert\Delta\tau_{ij}\rvert = 2\%$	$\lvert\Delta\tau_{ij}\rvert = 4\%$	$\lvert\Delta\tau_{ij}\rvert = 6\%$	$\lvert\Delta\tau_{ij}\rvert = 8\%$	$\lvert\Delta\tau_{ij}\rvert = 10\%$
ΔWel^{int}	0.86%	1.77%	2.74%	3.79%	4.89%
ΔWel^{seg}	0.73%	1.52%	2.38%	3.31%	4.33%
	(b) Welfare ratio: $\Delta Wel_{change} = \Delta Wel^{int}/\Delta Wel^{seg}$				
Baseline	1.174	1.161	1.153	1.143	1.131

Notes: This table displays the welfare changes in the baseline scenario. Panel (a) shows the welfare gains (in percent) for integrated markets and segmented markets, separately. Panel (b) shows the welfare ratio $\Delta Wel^{int}/\Delta Wel^{seg}$.

markets vary between 0.86% and 4.89%, depending on the size of liberalization. For segmented markets, the respective range is between 0.73% and 4.33%. To dense the patterns into a single number, we evaluate the ratio

$$\Delta Wel_{change} = \frac{\Delta Wel^{int}}{\Delta Wel^{seg}}. \tag{40}$$

According to Panel (b) of Table 3.2, the welfare ratio is strictly larger than one (e.g., $\Delta Wel_{change} = 1.174$) but decreasing in the size of liberalization. The intuition for higher welfare gains under

[24]Note that welfare also depends on the parameter σ. For $\sigma \to \infty$, prices collapse to marginal costs enforcing domestic firms to serve market j, while exports would be less profitable. Also, consumers would switch to domestic varieties. The number of domestic varieties would increase, overall varieties decrease and the resulting welfare gains would be lower than in our setting.

[25]In terms of the bilateral trade cost matrix, we set $\tau_{ii} = 1$ and $\tau_{ij} = 1.20$. For convenience, we write trade cost reductions in absolute terms $\Delta\tau_{ij} = \lvert\Delta\tau_{ij}\rvert > 0$, although the true change is negative.

integration is based on three arguments.

First, Panel (a) in Figure 3.5 shows that the price ratio is increasing as a result of the decline in trade costs, and converges to one. This implies a stronger price decline for segmented markets.[26] The rationale for the smaller decline in the single-pricing is its dependence on the domestic price for which there is no further trade cost decline.

Second, there is a similar convergence pattern in the export probability showing that a small price effect leads to a more than proportional rise in the export exposure for integrated markets (see Panel (b) of Figure 3.5).

Third, the additional friction in the pricing leads to an initially lower welfare level for integrated markets ($\text{Wel}^{int} = 5.633$) compared to segmented markets ($\text{Wel}^{seg} = 5.673$, see Table 3.8 in Appendix 3.C). An immediate implication of the preceding observations is that lower welfare costs make market entry profitable for low-productivity firms in integrated markets. On the other hand, high-productivity firms continue to serve all markets. Given the restricted supply of labor, there is a strong increase in the demand for labor which forces the least productive firms to exit the market. They are unable to afford the higher real wage which is a result of the decline in trade costs between markets. Formally, despite the larger welfare level for segmented markets given by $P_{j,int} > P_{j,seg}$, the larger percentage change is the result of a lower initial welfare level. However, the larger the drop in trade costs, the smaller are the differences between the two settings.

As expected, the number of domestic firms is decreasing in the trade liberalization. Conditional on trade liberalization, less productive firms leave the market, thus lowering the number of domestic firms in equilibrium. On the other hand, a larger number of foreign firms starts to serve market i, which outweighs the decline in the number of domestic firms. According to Figure 3.11 (see Appendix 3.C for details), segmented markets start with a smaller number of firms in the initial equilibrium. This is the result of a larger initial productivity and welfare level. For sufficiently large trade cost reductions, the difference between segmented and integrated prices vanishes, and the number of firms is even smaller for integrated markets.

The observed patterns are closely related to the variable markups. It is the combination of a single-pricing rule, and trade frictions with $\tau_{ij} > \tau_{ii}$, which ensures a larger domestic markup. This shifts the goods demand to the foreign consumers, for which the supply of goods must account in terms of iceberg trade losses. If trade costs are large, there is no effective shift towards foreign varieties. When trade costs decline, however, firms in market i start to serve market j, which requires a larger production, and leads to a co-movement in the demand for labor and real wages.

The effect of the fixed costs f_{ij}. We further account for the importance of market entry costs. Panel (a) in Table 3.3 shows the welfare ratio for different fixed costs f_{ij}. Similar to the baseline results, the welfare ratio is larger than one, yet a decreasing function of $|\Delta\tau_{ij}|$. Its ratio peaks at $f_{ii} = 1e^1$ across a wide range of trade cost changes.

The intuition is similar to the benchmark scenario: the initial welfare level is worse for integrated markets (see Table 3.8 in the Appendix), hence leading to higher welfare gains since the least productive firms leave the market. In addition, for both pricing regimes, Table 3.9 in Appendix 3.C shows that the welfare gains are increasing in the liberalization $|\Delta\tau_{ij}|$ (e.g., the gains for integrated markets vary between 1.58% and 8.22% for $f_{ij} = 1e^1$) but decreasing in the market entry costs f_{ij}. This is the result of the decreasing demand for labor which also leads to a lower increase in the real wage and thus, welfare.[27] Finally, Table 3.7 in Appendix 3.C complements the analysis in terms of the number of domestic firms. This number is larger for integrated markets due to the lower initial average productivity, as well as decreasing in the size of liberalization $|\Delta\tau_{ij}|$, and increasing in the market entry costs.

[26] The observed pattern is a direct result from the monopolistic competition setting, which makes firms attribute lower trade costs on a one-by-one basis to consumers.

[27] For a given trade cost level τ_{ij}, the number of firms is increasing in the size of fixed costs f_{ij}.

Table 3.3: Relative Welfare Gains for f_{ij} and J

	(a) Welfare ratio — Market entry costs f_{ij}				
	$\lvert\Delta\tau_{ij}\rvert = 2\%$	$\lvert\Delta\tau_{ij}\rvert = 4\%$	$\lvert\Delta\tau_{ij}\rvert = 6\%$	$\lvert\Delta\tau_{ij}\rvert = 8\%$	$\lvert\Delta\tau_{ij}\rvert = 10\%$
$f_{ij} = 1e^1$	1.276	1.240	1.217	1.197	1.179
$f_{ij} = 1e^2$	1.243	1.236	1.231	1.216	1.198
$f_{ij} = 1e^3$	1.174	1.162	1.153	1.143	1.131
$f_{ij} = 1e^4$	1.047	0.976	1.002	1.022	1.038
	(b) Welfare ratio — Number of markets J				
$J = 2$	1.299	1.276	1.240	1.230	1.194
$J = 4$	1.174	1.161	1.153	1.143	1.131
$J = 6$	1.123	1.121	1.114	1.108	1.102
$J = 8$	1.119	1.114	1.107	1.098	1.091
$J = 10$	1.102	1.084	1.084	1.080	1.075

Notes: This table displays welfare ratios $\Delta Wel^{int}/\Delta Wel^{seg}$ from trade liberalization. Panel (a) uses different market entry costs f_{ij}. Panel (b) uses different numbers of markets J.

The effect of the number of markets J. Table 3.3 shows the results for different numbers of markets $J = \{2, 4, 6, 8, 10\}$. The idea is that holding constant the aggregate labor force L, we increase the number of markets that share L and which each firm can potentially serve. Hence, trade liberalization affects the firms' decision towards a larger number of markets which remain symmetric. As such, the single-pricing and the induced interdependent market entry decision depend on the number of markets. The results show higher welfare gains for integrated markets (i.e., the welfare ratio is larger than one). The intuition is as before and indicates that the advantage in the welfare gains for integrated markets vanishes when the pricing friction is binding for a sufficiently large number of markets.

The complementary results (Tables 3.7, 3.8 and 3.10, Appendix 3.C) indicate further valuable insights. Firstly, the initial welfare, which is lower under integration, is also decreasing in the number of markets. The intuition is twofold. On the one hand, each firm needs to pay market entry costs for a larger number of destinations, while on the other hand, the share of labor available for market i, L_i is decreasing in the number of destinations, given the constant size L.

Second, the number of firms is larger for integrated markets, pointing to the worse (initial) competitiveness across borders, and is decreasing in both the number of destination markets and in the size $|\Delta\tau_{ij}|$.

3.6.4 Partial market integration

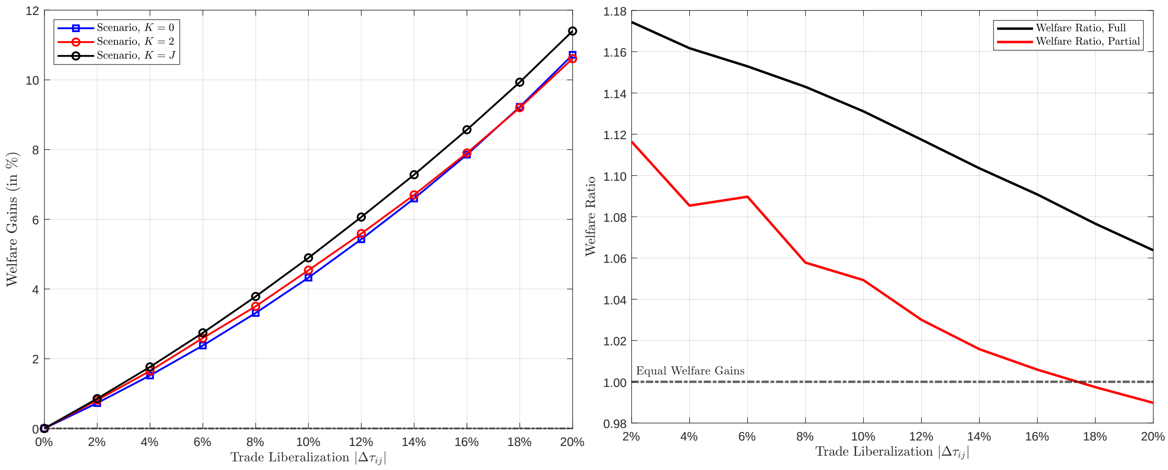
In this section, we relax the assumption of perfect integration and segmentation by determining the welfare gains for partially integrated markets in which the single-pricing rule applies to a subset of $K \subseteq J$ markets. As before, we assume $J = 4$ markets. Here, K defines the number of integrated markets, where apart from the two corner cases $K = 0$ (full segmentation) and $K = J$ (full integration), there is also the case with $K = 2$ integrated markets.[28]

We consider the same trade cost reductions as in the baseline scenario and display the results in Figure 3.7. From Panel (a), we learn that the welfare gains in all cases (fully integrated, partially integrated and fully segmented markets) are increasing in $|\Delta\tau_{ij}|$, while the welfare

[28]Note that the case with $K = 3$ would imply market integration for one market, which trivially reflects the scenario with fully market segmentation.

Figure 3.7: Welfare Gains: Partial Integration

(a) ΔWel (in percent) (b) $\Delta Wel^{(p)int}/\Delta Wel^{seg}$



Notes: This figure shows the welfare gains (in percent) as a function of the trade cost reduction $\Delta\tau_{ij}$. Panel (a) contains partially integrated markets ($K = 2$, red line), fully integrated markets ($K = J$, black line) and fully segmented markets ($K = 0$, blue line). Panel (b) shows the welfare ratio $\Delta Wel^{(p)int}/\Delta Wel^{seg}$, where the notation '*(p)int*' includes both partial integration and full integration.

gains for fully integrated markets are larger than for partial integration or market segmentation. The reason is that partial integration weakens the implications for fully integrated markets, in that the markup for foreign markets is weakened relative to fully integrated markets. For the remaining markets, there is the possibility of price discrimination, which lowers the opportunity to shift demand to the export markets. A second insight is that for certain trade cost reductions (above 18%) patterns even switch, and lead to higher welfare gains for segmented markets compared to partially integrated markets.

According to Panel (b) of Figure 3.7, the relative welfare gains of both partially and fully integrated markets — each relative to segmented markets — are declining and for partial integration even falling below the point of equal welfare gains. The patterns also become visible in terms of the number of firms. Figure 3.12 in Appendix 3.C shows an inverse relationship to the size of liberalization, i.e., the larger the decline in trade costs, the lower is the number of firms. Initially, the firm number of partially integrated markets lies between the values of segmented markets and integrated markets. For sufficiently large changes, this pattern flips, and the number of firms is lower for integrated markets than for partially integrated markets.

Summary. We conclude that firms in integrated markets charge (i) lower prices, (ii) are less likely to export, and (iii) earn lower aggregate expected profits. The observed patterns are positive functions of the trade barriers, resulting from the loss in the degrees of freedom when setting one price. We also find that market integration leads to higher welfare gains. This results from stronger self-selection of firms into exporting if trade costs decline compared to the standard model. However, this gap is a decreasing function of the trade cost reduction, $|\Delta\tau_{ij}|$, and can even reverse if markets are partially integrated and $|\Delta\tau_{ij}|$ is sufficiently large. We now transfer the results from symmetric to asymmetric markets.

3.7 Extensions and sensitivity analysis

In this section, we relax the symmetry assumption and extend the analysis to asymmetries in initial trade cost levels τ_{ij}, market entry costs f_{ij}, and the labor force L_i. In a final exercise, we show that the results are robust to the choice of the shape parameters (α, β) and the location parameters (a, b) of the respective Pareto distribution.

3.7.1 Welfare gains for asymmetric markets

Heterogeneous trade costs τ_{ij}. We begin by relaxing the symmetry assumption for the level of bilateral trade costs. In the benchmark scenario, all destinations other than the home market have been treated symmetrically by assuming a unique $\tau_{ij} > 1$, while for the home market, there are no frictions, i.e., trade costs were normalized to one ($\tau_{ii} = 1.00$).

We now consider an asymmetric trade costs scenario, where markets are assumed unequally distant to each other. We specify $\tau_{12} = \tau_{21} = 1.20$, $\tau_{13} = \tau_{31} = 1.22$ and $\tau_{14} = \tau_{41} = 1.24$, i.e., markets 1 and 2 are direct neighbors, similar to markets 2 and 3 with $\tau_{23} = \tau_{32} = 1.20$. The same logic applies to markets 3 and 4. On the other hand, markets 1 and 3 are further distant and the largest distance is between markets 1 and 4.

Panel (a) of Table 3.4 shows that the choice of lower trade costs for direct neighbors results in similar welfare ratios as in the benchmark case. Notably, the welfare changes are in the range of [0.72%, 4.70%] for integrated markets and [0.62%, 3.96%] for segmented markets, thus being smaller than in the benchmark case. This is partly the result of larger initial trade costs between some of the markets (see Table 3.11 in Appendix 3.C for further details).

Heterogeneous fixed costs f_{ij}. We further evaluate the impact of heterogeneous market entry costs f_{ij}. Plausibly, markets vary regarding the investment costs necessary to enter and serve the respective market. To model this scenario, we apply a similar logic as in the previous case by considering costs $f_{ij} = 1e^1$ for the home market, $f_{ij} = 1e^2$ for direct neighbors, $f_{ij} = 1e^3$ for indirect neighbors (e.g., markets 1 and 3) and finally, $f_{ij} = 1e^4$ for the most distant market pair (markets 1 and 4).

As Panel (a) of Table 3.4 shows, the choice of lower fixed costs for direct neighbors leads to similar welfare ratios, as in the benchmark case. The welfare gains range in the interval [1.45%, 7.45%] for integrated markets and [1.16%, 6.26%] for segmented markets (see Table 3.11 in Appendix 3.C for further details).

Heterogeneous market size L_i. In the last exercise, we determine the effect of heterogeneous market size L_i on the welfare gains for segmented and integrated markets. The rationale is to evaluate how different market sizes affect the distribution of welfare across markets when holding the aggregate size $L = \sum L_i$ constant. The labor supply vector changes to $L_i = [50, 50, 100, 200]$.

Panel (b) of Table 3.4 displays the welfare ratios for the upper bound ($L_i = 200$) and the lower bound ($L_i = 50$). Interestingly, the patterns in both markets are fairly stable, meaning that the ratio does not substantially decline in trade cost reductions.[29] It is more informative to look at the separate welfare gains between the market sizes.

For the larger market, the welfare gains are substantially smaller than for the small market. In numbers, a 2% decline in trade costs leads to welfare gains of 1.21% for $L_i = 50$, but only 0.48% for the large market for integrated markets (see Table 3.12 in Appendix 3.C). The patterns are similar to those under segmentation. The effect is driven by a smaller real wage effect for the large market, given the larger labor supply. Since this effect is persistent across different scenarios $|\Delta\tau_{ij}|$ and similar for integrated and segmented markets, the related ratio remains stable, too.

3.7.2 Robustness checks for the Pareto distribution

To check the sensitivity our results to the choice of the parameter values, we change shape parameters (α, β) and the location parameters (a, b) of the respective Pareto distributions.

[29] As an exception, the welfare ratio decreases for a large decline of 20%.

Table 3.4: Extension: Heterogeneity in τ_{ij}, f_{ij} and L_i

	(a) Welfare ratio — f_{ij}^{het} and τ_{ij}^{het}				
	$\|\Delta\tau_{ij}\| = 2\%$	$\|\Delta\tau_{ij}\| = 4\%$	$\|\Delta\tau_{ij}\| = 6\%$	$\|\Delta\tau_{ij}\| = 8\%$	$\|\Delta\tau_{ij}\| = 10\%$
τ_{ij}^{het}	1.165	1.233	1.215	1.199	1.185
fij^{het}	1.249	1.222	1.227	1.207	1.190
	(b) Welfare ratio — $L_i = [50, 50, 100, 200]$				
$L_i = 50$	1.101	1.129	1.116	1.111	1.120
$L_i = 200$	1.215	1.186	1.217	1.218	1.200

Notes: This table displays the welfare ratios $\Delta Wel^{int}/\Delta Wel^{seg}$ for asymmetric markets. Panel (a) considers heterogeneity in both trade cost levels τ_{ij} and market entry costs f_{ij}. Panel (b) considers an asymmetric labor size L_i for the upper and lower bound.

Table 3.5: Robustness: Shape Parameter (α, β)

	(a) Welfare ratio — Shape Parameter α				
	$\|\Delta\tau_{ij}\| = 2\%$	$\|\Delta\tau_{ij}\| = 4\%$	$\|\Delta\tau_{ij}\| = 6\%$	$\|\Delta\tau_{ij}\| = 8\%$	$\|\Delta\tau_{ij}\| = 10\%$
$\alpha = 2$	1.192	1.179	1.173	1.155	1.140
$\alpha = 3$	1.174	1.161	1.153	1.143	1.131
$\alpha = 4$	1.181	1.175	1.165	1.153	1.142
	(b) Welfare ratio — Shape Parameter β				
$\beta = 2.5$	1.184	1.169	1.154	1.141	1.128
$\beta = 3$	1.174	1.161	1.153	1.143	1.131
$\beta = 3.5$	1.162	1.144	1.149	1.142	1.136

Notes: This table shows the welfare ratios $\Delta Wel^{int}/\Delta Wel^{seg}$ for different shape parameters. Panel (a) changes parameter α. Panel (b) changes parameter β. In each panel, we deviate from the main specification only in the respective dimension.

Larger shape parameters assign more density mass to smaller values of the respective productivity. Table 3.5 displays the results. According to Panel (a), changes in the shape parameter of the stochastic fixed costs, α, lead to minor changes. For $\alpha = 2$ and $\alpha = 4$, the patterns are mostly stable with welfare ratios larger than one, yet decreasing in the size of the trade cost change. Panel (b) shows the respective results for the shape parameter β of the productivity level distribution. For $\beta = 2.5$, the welfare ratio is larger than for the baseline specification, confirming the insight that integrated markets have higher welfare gains. On the other hand, for $\beta = 3.5$, the pattern remains valid, too. From the complementing welfare gains (Tables 3.13 and 3.14 in Appendix 3.C), we infer that only variation in β changes the size of the welfare gains by a factor of two while preserving the overall pattern.

The results are robust to the choice of the location parameters (a, b). Intuitively, location parameters denote the left edge of distributions. Smaller values of a reflect smaller stochastic fixed costs, which translate into larger overall fixed costs, and thus, negatively affect in particular low-productivity firms. The competition for labor declines, which also drives down related welfare gains and its ratio, as Panel (a) in Table 3.6 confirms. The pattern reverses for the

Table 3.6: Robustness: Location Parameter (a, b)

	(a) Welfare ratio — Location Parameter a				
	$\|\Delta\tau_{ij}\| = 2\%$	$\|\Delta\tau_{ij}\| = 4\%$	$\|\Delta\tau_{ij}\| = 6\%$	$\|\Delta\tau_{ij}\| = 8\%$	$\|\Delta\tau_{ij}\| = 10\%$
$a = 8$	1.168	1.158	1.149	1.139	1.128
$a = 9$	1.168	1.162	1.153	1.138	1.127
$a = 10$	1.174	1.161	1.153	1.143	1.131
	(b) Welfare ratio — Location Parameter b				
$b = 1$	1.204	1.153	1.159	1.155	1.142
$b = 2$	1.174	1.161	1.153	1.143	1.131
$b = 3$	1.160	1.140	1.131	1.120	1.108

Notes: This table shows the welfare ratios $\Delta Wel^{int}/\Delta Wel^{seg}$ for different location parameters. Panel (a) changes parameter a. Panel (b) changes parameter b. In each panel, we deviate from the main specification only in the respective dimension.

location parameter b. In particular, smaller values indicate that more density mass is at low-productivity levels, which benefit more from trade liberalization. This leads to an increase in the welfare gains and the ratio. Panel (b) of Table 3.6 confirms our intuition by showing higher welfare gains for larger values of b. Yet, the magnitude and the qualitative patterns are robust.[30]

3.8 Conclusion

Two crucial questions in the light of proceeding market integration are 'How would price integration affect the export decision of heterogeneous firms?' and 'What are the implications for the welfare of the overall economy?' Both these questions have important real-world applications in either the international trade context with cross- border arbitrage or in the national context where firms charge one price in different markets despite facing heterogeneous distribution costs (e.g., in the Retail business, see DellaVigna and Gentzkow, 2019).

To compare integrated and segmented markets in a heterogeneous-firm model, we extend the model class around Melitz (2003), forcing firms to set one price for all its destinations. This leads to a world where market entry is interdependent since the optimal pricing and market entry decision for one market is a function of wages, income levels, and export decisions from all markets. To solve the model for an arbitrary number of markets, we introduce novel stochastic fixed costs that lead to a probabilistic representation of fixed costs. The respective market entry becomes a function of the chosen price, which creates market interdependence given that the price is a function of all market entry choices.

We evaluate the effects of price integration both on firm-specific choices and the aggregate economy. Using a stylized calibration, we show that price integration makes firms charge a lower price, lowers their probability to export, and leads to lower expected aggregate profits than in the case of segmented markets. The main explanation is that the price is an average of all market-specific prices. The limiting effects of losing price-setting freedom are more severe for low-productivity firms and in a world with larger trade frictions. On the other hand, this mechanism does not affect high-productivity firms. Although a single-pricing mechanism is a crucial step in forming a single market, one takeaway is that integration comes at a cost for low-productivity firms and larger markets.

[30] We display the original welfare changes for integrated and segmented markets in Table 3.15 (for location parameter a) and Table 3.16 (for location parameter b), both in Appendix 3.C.

In a second exercise, we quantify the welfare gains from trade liberalization for both settings. When trade costs decline, we observe higher welfare gains for integrated markets since the low-productivity firms find it now profitable to enter the export market, which leads to an increase in the demand for labor. This induces a stricter self-selection mechanism in line with Bernard et al. (2007a) and Melitz (2003). Further, the single-pricing mechanism yields non-constant markups, which shift the demand from the home market towards goods produced in foreign markets and increase the respective production subject to iceberg trade costs. A different perspective is that charging a single price leads to a second friction besides bilateral trade frictions. An immediate implication is an initially lower welfare level combined with a catch-up effect, which results in higher welfare gains.

In a third exercise, we show that the effects are robust to partially integrated markets and various extensions with, e.g., asymmetries in bilateral trade costs, market entry costs and the labor force. The main lesson is that price integration heterogeneously affects firms of different productivity levels and matters for the welfare gains of trade liberalization. In particular, low-productivity firms are initially worse-off but benefit more than proportional from trade liberalization. By design, our model captures a mechanism to frame interdependent market entry, which can be adopted in other settings, where market integration is crucial.

Appendix 3.A Model derivations

This section presents detailed derivations of the model used in the main text. Throughout, we use the notation $p_{i(j)}$ to denote the price level for both integrated markets (p_i) and segmented markets (p_{ij}) when the respective step applies to both settings.

To derive the profit maximizing price, first note that the market-specific profits are given by

$$\pi_{ij}(\phi, \epsilon_{ij}) = p_{i(j)}(\phi)^{1-\sigma} w_j L_j P_j^{\sigma-1} - p_{i(j)}(\phi)^{-\sigma} w_j L_j P_j^{\sigma-1} \frac{w_i \tau_{ij}}{\phi} - \frac{1}{\epsilon_{ij}} w_i f_{ij} \tag{3.A.1}$$

To streamline notation, we define

$$V_{ij}(\phi) \equiv \frac{\left(p_{i(j)}(\phi)^{1-\sigma} - p_{i(j)}(\phi)^{-\sigma} \frac{w_i \tau_{ij}}{\phi}\right) w_j L_j P_j^{\sigma-1}}{w_i f_{ij}} \tag{3.A.2}$$

Then, the partial derivative $V'_{ij}(\phi) = \partial V_{ij}(\phi) / \partial p_{i(j)}(\phi)$ can be written as:

$$V'_{ij}(\phi) = \frac{w_j L_j P_j^{\sigma-1}}{w_i f_{ij}} \left[(1-\sigma) p_{i(j)}(\phi)^{-\sigma} + \sigma p_{i(j)}(\phi)^{-\sigma-1} \frac{w_i \tau_{ij}}{\phi}\right] \tag{3.A.3}$$

A given firm does not automatically export in every destination market. Rather, based on the stochastic fixed cost draw, the firm serves market j if and only if

$$\left(p_{i(j)}(\phi)^{1-\sigma} - p_{i(j)}(\phi)^{-\sigma} \frac{w_i \tau_{ij}}{\phi}\right) w_j L_j P_j^{\sigma-1} \frac{w_i \tau_{ij}}{\phi} \geq \frac{1}{\epsilon_{ij}} w_i f_{ij}. \tag{3.A.4}$$

This leads to the sufficient condition to export

$$\epsilon_{ij} \geq \frac{w_j f_{ij}}{\left(p_{i(j)}(\phi)^{1-\sigma} - p_{i(j)}(\phi)^{-\sigma} \frac{w_i \tau_{ij}}{\phi}\right) w_j L_j P_j^{\sigma-1}} \tag{3.A.5}$$

We can derive the probability for a firm with productivity ϕ to export from market i into market j by noting that

$$\mathbf{I}_{ij}(\phi) = \Pr(\epsilon_{ij} \geq \epsilon_{ij}^*) = 1 - F\left(\frac{1}{V_{ij}(\phi)}\right) = 1 - \left(1 - \frac{a^\alpha}{\epsilon_{ij}^{*\alpha}}\right) = a^\alpha V_{ij}(\phi)^\alpha, \tag{3.A.6}$$

where we have used the relationship $\epsilon_{ij}^* = 1/V_{ij}(\phi)$. Note also that a second possible interpretation of the term $\mathbf{I}_{ij}(\phi)$ is the firm share — with productivity ϕ — which sells its variety from market i to market j. This probability must be bounded in $[0, 1]$. Recall that

$$\pi_{ij}(\phi, \epsilon_{ij}) = p_{i(j)}(\phi)^{1-\sigma} Y_j P_j^{\sigma-1} - p_{i(j)}(\phi)^{-\sigma} Y_j P_j^{\sigma-1} \frac{w_i \tau_{ij}}{\phi} - \frac{1}{\epsilon_{ij}} w_i f_{ij} \tag{3.A.7}$$

$$\Pi_i(\phi) = \sum_j p_{i(j)}(\phi)^{1-\sigma} Y_j P_j^{\sigma-1} - p_{i(j)}(\phi)^{-\sigma} Y_j P_j^{\sigma-1} \frac{w_i \tau_{ij}}{\phi} - \frac{1}{\epsilon_{ij}} w_i f_{ij} \tag{3.A.8}$$

To derive equation (20), we calculate the expected profits with regard to ϵ_{ij}, which is given by

$$\mathbb{E}_\epsilon(\Pi_i(\phi)) = \sum_j \mathbf{I}_{ij}(\phi) \left[V_{ij} w_j f_{ij} - \mathbb{E}_\epsilon\left(\frac{1}{\epsilon_{ij}} | \epsilon_{ij} \geq \epsilon_{ij}^*\right) w_i f_{ij}\right]. \tag{3.A.9}$$

Using $\mathbf{I}_{ij}(\phi) = \Pr(\epsilon_{ij} = \epsilon_{ij}^*) = a^\alpha/\epsilon^{\alpha^*} = a^\alpha V_{ij}^\alpha$, this expression becomes

$$\mathbb{E}_\epsilon(\Pi_i(\phi)) = \sum_j a^\alpha V_{ij}^\alpha \left[V_{ij} w_j f_{ij} - \mathbb{E}_\epsilon \left(\frac{1}{\epsilon_{ij}} | \epsilon_{ij} \geq \epsilon_{ij}^* \right) w_i f_{ij} \right]. \tag{3.A.10}$$

The conditional density function ensures that only firms with non-negative profits serve each market. Conditional on exporting, we obtain for the 'probability density function' (pdf)

$$f(\epsilon_{ij}|\epsilon_{ij} \geq \epsilon_{ij}^*) = \frac{f(\epsilon_{ij})}{1 - F(\epsilon_{ij}^*)} = \frac{\alpha a^\alpha}{\epsilon_{ij}^{\alpha+1}} \left(\frac{a^\alpha}{\epsilon^{*\alpha}} \right)^{-1} = \frac{\alpha}{\epsilon_{ij}^{\alpha+1}} V_{ij}^{-\alpha}.$$

The conditional expectation of the respective term $1/\epsilon_{ij}$ is then given by

$$\mathbb{E}_\epsilon \left(\frac{1}{\epsilon_{ij}} | \epsilon_{ij} \geq \epsilon_{ij}^* \right) = \int_{\epsilon_{ij}^*}^\infty \frac{1}{\epsilon_{ij}} f(\epsilon | \epsilon_{ij} \geq \epsilon_{ij}^*)) d\epsilon = \int_{\epsilon_{ij}^*}^\infty \frac{1}{\epsilon_{ij}} \frac{\alpha}{\epsilon_{ij}^{\alpha+1}} V_{ij}^{-\alpha} d\epsilon$$

Plugging this relationship into (3.A.9) delivers the expected aggregate profits as a function of productivity (ϕ) as determined by equation (20). Spelled out, we obtain

$$\mathbb{E}_\epsilon(\Pi_i(\phi)) = \sum_j \mathbf{I}_{ij}(\phi) \left[V_{ij} w_j f_{ij} - \mathbb{E}_\epsilon \left(\frac{1}{\epsilon_{ij}} | \epsilon_{ij} \geq \epsilon_{ij}^* \right) w_i f_{ij} \right] \tag{3.A.11}$$

$$= \sum_j a^\alpha V_{ij}^\alpha \left[V_{ij} w_j f_{ij} - \left(\int_{\epsilon_{ij}^*}^\infty \frac{1}{\epsilon_{ij}} \frac{\alpha}{\epsilon_{ij}^{\alpha+1}} V_{ij}^{-\alpha} d\epsilon \right) w_i f_{ij} \right] \tag{3.A.12}$$

$$= \sum_j a^\alpha V_{ij}^\alpha \left[V_{ij} w_i f_{ij} - w_i f_{ij} V_{ij}^{-\alpha} \alpha \left[\frac{1}{-\alpha - 1} \epsilon_{ij}^{-\alpha-1} \Big|_{1/V_{ij}}^\infty \right] \right] \tag{3.A.13}$$

$$= \sum_j a^\alpha V_{ij}^\alpha \left[V_{ij} w_i f_{ij} - w_i f_{ij} V_{ij}^{-\alpha} \alpha \left(0 - \frac{1}{-(\alpha+1)} V_{ij}^{\alpha+1} \right) \right] \tag{3.A.14}$$

$$= \sum_j a^\alpha V_{ij}^\alpha \left[V_{ij} w_i f_{ij} - \frac{\alpha}{\alpha+1} V_{ij} w_i f_{ij} \right] \tag{3.A.15}$$

We can further simplify this expression — using in the last step $\Pr(\epsilon_{ij} > \epsilon_{ij}^*) = a^\alpha V_{ij}^\alpha$ — to see

$$\mathbb{E}_\epsilon(\Pi_i(\phi)) = \sum_j a^\alpha V_{ij}^\alpha \left[\frac{1}{\alpha+1} V_{ij} w_i f_{ij} \right] \tag{3.A.16}$$

$$= \sum_j \left(\frac{1}{\alpha+1} \right) a^\alpha V_{ij}^{\alpha+1} w_i f_{ij}. \tag{3.A.17}$$

Optimal price $p_i(\phi)$ for integrated markets. Now, we can solve for the optimal price by taking the first-order condition of the aggregate expected profits given price $p_i(\phi)$ charged by firm with productivity level ϕ in location i. This leads to

$$\frac{\partial \mathbb{E}_\epsilon(\Pi_i(\phi))}{\partial p_i(\phi)} = \sum_j a^\alpha V_{ij}^\alpha V_{ij}' w_i f_{ij} \stackrel{!}{=} 0 \tag{3.A.18}$$

Note that market interdependence allows for no closed form solution. Instead, we end with an implicit function which requires numerical solutions (using the MATLAB routine *fminsearch*).

Optimal price $p_{ij}(\phi)$ for segmented markets. For segmented markets, we take the first-order condition with respect to the market-specific pricing $p_{ij}(\phi)$. This delivers

$$\frac{\partial \mathbb{E}_\epsilon(\Pi_i(\phi))}{\partial p_{ij}(\phi)} = a^\alpha V_{ij}^\alpha V_{ij}' w_i f_{ij} \stackrel{!}{=} 0 \tag{3.A.19}$$

The nontrivial solution, for which $w_i = f_{ij} = a^\alpha \neq 0$, is based on the condition

$$V_{ij}(\phi)^\alpha V_{ij}'(\phi) \stackrel{!}{=} 0. \tag{3.A.20}$$

Recalling that

$$V_{ij}(\phi) = \frac{w_j L_j P_j^{\sigma-1}}{w_i f_{ij}} \left(p_{ij}(\phi)^{1-\sigma} - p_{ij}(\phi)^{-\sigma} \frac{w_i \tau_{ij}}{\phi} \right) \tag{3.A.21}$$

$$V_{ij}'(\phi) = \frac{w_j L_j P_j^{\sigma-1}}{w_i f_{ij}} \left[(1-\sigma) p_{ij}(\phi)^{-\sigma} + \sigma p_{ij}(\phi)^{-\sigma-1} \frac{w_i \tau_{ij}}{\phi} \right] \tag{3.A.22}$$

we obtain two potential solutions by additionally simplifying expressions to

$$\frac{\partial \mathbb{E}_\epsilon(\Pi_i(\phi))}{\partial p_{ij}(\phi)} = \left[p_{ij}(\phi) - \frac{w_i \tau_{ij}}{\phi} \right]^\alpha \left[(1-\sigma) + \sigma p_{ij}(\phi)^{-1} \frac{w_i \tau_{ij}}{\phi} \right] = 0. \tag{3.A.23}$$

The left-hand side becomes zero if $p_{ij}(\phi) = w_i \tau_{ij}/\phi$ or if $p_{ij}(\phi) = [\sigma/(\sigma-1)]\, w_i \tau_{ij}/\phi$. To show which of the two solutions corresponds to a profit maximum, we evaluate the second derivative at each point. We have

$$\frac{\partial^2 \mathbb{E}_\epsilon(\Pi_i(\phi))}{\partial p_{ij}(\phi)^2} = (1-\sigma) + \sigma \left(\frac{w_i \tau_{ij}}{\phi} \right)^2 p_{ij}(\phi)^{-2}.$$

Evaluating the second derivative at $p_{ij}(\phi) = w_i \tau_{ij}/\phi$, we get

$$\frac{\partial^2 \mathbb{E}_\epsilon(\Pi_i(\phi))}{\partial p_{ij}(\phi)^2} \Big|_{\frac{w_i \tau_{ij}}{\phi}} = 1 - \sigma + \sigma = 1 > 0 \tag{3.A.24}$$

indicating a minimum. Evaluated at $p_{ij}(\phi) = [\sigma/(\sigma-1)]\, w_i \tau_{ij}/\phi$ delivers

$$\frac{\partial^2 \mathbb{E}_\epsilon(\Pi_i(\phi))}{\partial p_{ij}(\phi)^2} \Big|_{\frac{\sigma}{\sigma-1}\frac{w_i \tau_{ij}}{\phi}} = -\frac{\sigma-1}{\sigma} < 0. \tag{3.A.25}$$

This proofs that under perfectly segmented markets, firms set $p_{ij}(\phi) = [\sigma/(\sigma-1)]\, w_i \tau_{ij}/\phi$ to maximize profits.

Zero-cutoff profit condition. The zero-cutoff profit condition (ZCP) states that the firm with the cutoff productivity makes zero profit. Using the relationship $\epsilon_{ij}^* = 1/V_{ij}$,

$$\pi_{ij}(\phi_{ij}^*) = V_{ij} w_i f_{ij} - \frac{1}{\epsilon_{ij}^*} w_i f_{ij} = V_{ij} w_i f_{ij} - V_{ij} w_i f_{ij} = 0. \tag{3.A.26}$$

To determine the trade share λ_{ij} and derive the gravity equation, first note that the quantity that country j spends on the variety produced by firm ϕ in country i is given by:

$$x_{ij}(\phi) = \frac{p_{i(j)}(\phi)^{1-\sigma}}{P_j^{1-\sigma}} Y_j = \frac{p_{i(j)}(\phi)^{1-\sigma}}{P_j^{1-\sigma}} E_j \tag{3.A.27}$$

Aggregate trade flows for integrated markets. We aggregate the bilateral flows across all firms N_i and productivity levels. This delivers the following aggregate trade flows for (i, j),

$$X_{ij} \equiv \int_{\Omega_i} x_{ij}(\omega) d\omega = Y_j P_j^{\sigma-1} N_i \int_{\underline{\phi}_i}^{\infty} \mathbf{I}_{ij}(\phi) p_i(\phi)^{1-\sigma} f(\phi) d\phi. \tag{3.A.28}$$

With the aggregate trade flows at hand, we next determine the trade share λ_{ij}, which gives us the fraction of goods (or expenditures) of overall j's spending spent on goods from (exporting) country i (see Costinot and Rodríguez-Clare, 2014). Formally,

$$\lambda_{ij} = \frac{X_{ij}}{\sum_k X_{kj}} = \frac{N_i Y_j P_j^{\sigma-1} \int_{\underline{\phi}_i}^{\infty} \mathbf{I}_{ij}(\phi) p_i(\phi)^{1-\sigma} f(\phi) d\phi}{\sum_k N_k Y_j P_j^{\sigma-1} \int_{\underline{\phi}_i}^{\infty} I_{kj}(\phi) p_k(\phi)^{1-\sigma} f(\phi) d\phi} \tag{3.A.29}$$

$$= \frac{Y_j P_j^{\sigma-1} N_i \int_{\underline{\phi}_i}^{\infty} \mathbf{I}_{ij}(\phi) p_i(\phi)^{1-\sigma} f(\phi) d\phi}{Y_j P_j^{\sigma-1} \sum_k N_k \int_{\underline{\phi}_i}^{\infty} I_{kj}(\phi) p_k(\phi)^{1-\sigma} f(\phi) d\phi} \tag{3.A.30}$$

This expression can be further simplified to:

$$\lambda_{ij} = \frac{N_i \int_{\underline{\phi}_i}^{\infty} \mathbf{I}_{ij}(\phi) p_i(\phi)^{1-\sigma} f(\phi) d\phi}{\sum_k N_k \int_{\underline{\phi}_i}^{\infty} I_{kj}(\phi) p_k(\phi)^{1-\sigma} f(\phi) d\phi} \tag{3.A.31}$$

$$= \frac{N_i \int_{\underline{\phi}_i}^{\infty} \mathbf{I}_{ij}(\phi) p_i(\phi)^{1-\sigma} f(\phi) d\phi}{P_j^{1-\sigma}} \tag{3.A.32}$$

Here, X_{ij} denotes the spending of (importer) j on goods from (exporter) i and $\sum_k X_{kj}$ denotes the overall spending of (importer) j, that is $E_j = \sum_i X_{ij}$. The relationship for the aggregate price index P_j for importing country j is given by

$$P_j = \left(\sum_{k \in J} \int_{\underline{\phi}_k}^{\infty} N_k p_{k(j)}(\phi)^{1-\sigma} \mathbf{I}_{kj}(\phi) f(\phi) d\phi \right)^{\frac{1}{1-\sigma}} \tag{3.A.33}$$

where due to market interdependence $p_{k(j)}(\omega) = p_k(\omega)$, $\forall j \in J$, $\mathbf{I}_{kj}(\phi) = a^{\alpha} V_{kj}^{\alpha}$ denotes the probability of exporting to market j, and N_k denotes the number of firms in exporting region k. To calculate $P_j \equiv \left(\sum_k \int_{\Omega_k} p_k(\omega)^{1-\sigma} d\omega \right)^{1-\sigma}$, recall that market j buys from all $k \in J$. Hence,

$$\sum_{k \in J} \int_{\Omega_k} p_k(\omega)^{1-\sigma} d\omega = \sum_{k \in J} N_k \int_{\underline{\phi}_k}^{\infty} p_k(\phi)^{1-\sigma} \mathbf{I}_{kj}(\phi) f(\phi) d\phi \tag{3.A.34}$$

Aggregate trade flows for segmented markets. Similar to the integrated market scenario, we start by determining the aggregate trade flows traded between country i and country j.

$$X_{ij} \equiv \int_{\Omega_i} x_{ij}(\omega) d\omega = Y_j P_j^{\sigma-1} N_i \int_{\underline{\phi}_i}^{\infty} \mathbf{I}_{ij}(\phi) p_{ij}(\phi)^{1-\sigma} d\phi. \tag{3.A.35}$$

The main difference is that in the case of market segmentation, we have derived an explicit market-specific price $p_{ij} = \frac{\sigma}{\sigma-1} \frac{w_i \tau_{ij}}{\phi}$. Plugging in this expression and simplifying, we obtain

$$X_{ij} = Y_j P_j^{\sigma-1} N_i \int_{\underline{\phi}_i}^{\infty} \mathbf{I}_{ij}(\phi) \left(\frac{\sigma}{\sigma-1} \frac{w_i \tau_{ij}}{\phi} \right)^{1-\sigma} d\phi. \tag{3.A.36}$$

A little bit of algebra leads to the following expression

$$X_{ij} = \left(\frac{\sigma}{\sigma-1}\frac{w_i\tau_{ij}}{\phi}\right)^{1-\sigma} Y_j P_j^{\sigma-1} N_i \int_{\underline{\phi}_i}^{\infty} \mathbf{I}_{ij}(\phi)\phi^{\sigma-1}d\phi. \tag{3.A.37}$$

Notice that it is more involved to solve for the average productivity of the exporting markets as in Melitz (2003). The reason is that the pricing rule is extended by the probability to export, $\mathbf{I}_{ij}(\phi)$, which itself is a function of the market-specific price $p_{ij}(\phi)$ and the productivity level ϕ. This makes it hard to isolate the productivity level ϕ. With the respective aggregate trade flows, we determine the trade share λ_{ij} similar to the scenario with market interdependence.

$$\lambda_{ij} = \frac{X_{ij}}{\sum_k X_{kj}} = \frac{N_i Y_j P_j^{\sigma-1}\int_{\underline{\phi}_i}^{\infty}\mathbf{I}_{ij}(\phi)p_{ij}(\phi)^{1-\sigma}f(\phi)d\phi}{\sum_k N_k Y_j P_j^{\sigma-1}\int_{\Phi}\mathbf{I}_{kj}(\phi)p_{kj}(\phi)^{1-\sigma}f(\phi)d\phi} \tag{3.A.38}$$

$$= \frac{N_i \int_{\underline{\phi}_i}^{\infty}\mathbf{I}_{ij}(\phi)p_{ij}(\phi)^{1-\sigma}f(\phi)d\phi}{P_j^{1-\sigma}} \tag{3.A.39}$$

where the region-specific price is given by $p_{ij}(\phi) = [\sigma/(\sigma-1)]w_i\tau_{ij}/\phi$.

Derivation of further general equilibrium conditions

Free entry condition. We start with the free entry condition, which states that the average profits must be sufficiently high to cover the lottery costs. To derive the equation, we note that the expected profits are given by

$$\mathbb{E}_{\phi}(\Pi_i(\phi)) = \sum_j \left(\frac{1}{\alpha+1}\right) a^{\alpha} V_{ij}^{\alpha+1} w_i f_{ij}. \tag{3.A.40}$$

Rewriting this expression by using $a^{\alpha}V_{ij}^{\alpha} = \mathbf{I}_{ij}(\phi)$, using the relationship $a^{\alpha}V_{ij}^{\alpha+1} = a^{\alpha}V_{ij}^{\alpha}V_{ij} = \mathbf{I}_{ij}(\phi)V_{ij}$, and taking into account the distribution of ϕ, we obtain

$$\mathbb{E}_{\phi}(\Pi_i(\phi)) = \sum_j \int_{\Phi}\left(\frac{1}{\alpha+1}\right)\mathbf{I}_{ij}(\phi)V_{ij}w_i f_{ij} f(\phi)d\phi \overset{!}{=} w_i f_i^e. \tag{3.A.41}$$

Rearranging terms yields the free entry condition of the main text:

$$\mathbb{E}_{\phi}(\Pi_i(\phi)) = \left(\frac{1}{\alpha+1}\right)\sum_j \int_{\Phi}\mathbf{I}_{ij}(\phi)V_{ij}w_i f_{ij} f(\phi)d\phi \overset{!}{=} w_i f_i^e. \tag{3.A.42}$$

Labor market clearing condition. We continue with the labor market which requires that labor supply equals labor demand. In particular, labor participates in the lottery, produces a distinct variety of goods, and is used to pay the market entry costs f_{ij}. Formally, the relation follows Melitz (2003), which leaves for the labor demand of a single firm

$$\text{Foreign:}\quad l_i = e_i + f_{ij} + \frac{q_{ij}(\phi)}{\phi}\tau_{ij} \qquad\qquad \text{Domestic:}\quad l_i = e_i + f_{ij} + \frac{q_{ij}(\phi)}{\phi}$$

For the aggregate economy, we need to aggregate across firms. Formally,

$$L_i = N_i f_i^e + N_i \sum_j \int_{\underline{\phi}_i}^{\infty} \mathbf{I}_{ij}(\phi)\frac{p_{i(j)}(\phi)^{-\sigma}\tau_{ij}}{\phi} Y_j P_j^{\sigma-1} f(\phi)d\phi + N_i \sum_j \int_{\underline{\phi}_i}^{\infty} \mathbf{I}_{ij}(\phi) f_{ij} f(\phi)d\phi \tag{3.A.43}$$

Multiplication by the wage w_i yields

$$w_i L_i = N_i f_i^e w_i + N_i \sum_j \int_{\underline{\phi}_i}^{\infty} \mathbf{I}_{ij}(\phi) \frac{p_{i(j)}(\phi)^{-\sigma} w_i \tau_{ij}}{\phi} Y_j P_j^{\sigma-1} f(\phi) d\phi + N_i \sum_j \int_{\underline{\phi}_i}^{\infty} \mathbf{I}_{ij}(\phi) w_i f_{ij} f(\phi) d\phi \tag{3.A.44}$$

Rearranging[31] this equation then yields

$$w_i L_i - N_i \sum_j \int_{\underline{\phi}_i}^{\infty} \mathbf{I}_{ij}(\phi) \frac{p_{i(j)}(\phi)^{-\sigma} w_i \tau_{ij}}{\phi} Y_j P_j^{\sigma-1} f(\phi) d\phi = N_i f_i^e w_i + N_i \sum_j \int_{\underline{\phi}_i}^{\infty} \mathbf{I}_{ij}(\phi) w_i f_{ij} f(\phi) d\phi. \tag{3.A.45}$$

Trade Balance Condition. We use this equation and plug in the trade balance relationship

$$w_i L_i = (1+\alpha) N_i f_i^e w_i + N_i \sum_j \int_{\underline{\phi}_i}^{\infty} \mathbf{I}_{ij}(\phi) \frac{p_{i(j)}(\phi)^{-\sigma} w_i \tau_{ij}}{\phi} Y_j P_j^{\sigma-1} f(\phi) d\phi \tag{3.A.46}$$

to obtain

$$(1+\alpha) N_i f_i^e w_i = N_i f_i^e w_i + N_i \sum_j \int_{\underline{\phi}_i}^{\infty} \mathbf{I}_{ij}(\phi) w_i f_{ij} f(\phi) d\phi \tag{3.A.47}$$

Next, we plug in the free entry condition: $f_i^e w_i = (1/(1+\alpha)) \sum_j \int_{\underline{\phi}_i}^{\infty} \mathbf{I}_{ij}(\phi) V_{ij} w_i f_{ij} f(\phi) d\phi$, to derive the relationship

$$N_i \sum_j \int_{\underline{\phi}_i}^{\infty} \mathbf{I}_{ij}(\phi) V_{ij} w_i f_{ij} f(\phi) d\phi = N_i f_i^e w_i + N_i \sum_j \int_{\underline{\phi}_i}^{\infty} \mathbf{I}_{ij}(\phi) w_i f_{ij} f(\phi) d\phi. \tag{3.A.48}$$

Dividing by the number of firms, N_i we obtain

$$\sum_j \int_{\underline{\phi}_i}^{\infty} \mathbf{I}_{ij}(\phi) V_{ij} w_i f_{ij} f(\phi) d\phi = f_i^e w_i + \sum_j \int_{\underline{\phi}_i}^{\infty} \mathbf{I}_{ij}(\phi) w_i f_{ij} f(\phi) d\phi. \tag{3.A.49}$$

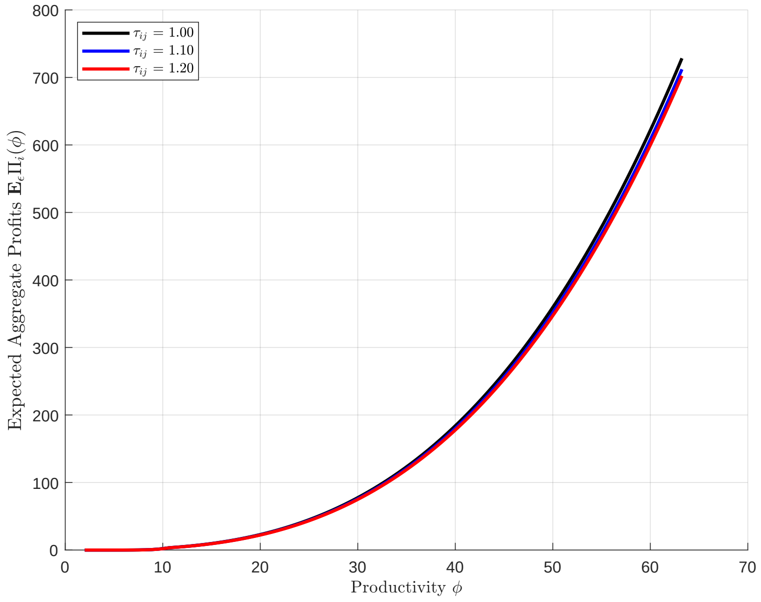
To derive the final equation, we plug in the free entry condition for $f_i^e w_i$ to get

$$\frac{\alpha}{\alpha+1} \sum_j \int_{\underline{\phi}_i}^{\infty} \mathbf{I}_{ij}(\phi) V_{ij} w_i f_{ij} f(\phi) d\phi = \sum_j \int_{\underline{\phi}_i}^{\infty} \mathbf{I}_{ij}(\phi) w_i f_{ij} f(\phi) d\phi \tag{3.A.50}$$

[31] A different notation splits the respective terms, leaving us with the following result: $l(\phi) = f_e + \mathbb{1}_d(\Delta(\sigma-1)B\phi^{\sigma-1} + f) + \mathbb{1}_x(\Delta(\sigma-1)B\tau^{1-\sigma}\phi^{\sigma-1} + f_x)$ where we use $B = P^\sigma Q$ with $Q \equiv U$ and $\Delta = \sigma^{-\sigma}(\sigma-1)^{\sigma-1}$. Recall that the CES price index P denotes the expenditure to receive one unit of utility. Hence, $U = \frac{E}{P} \equiv 1$. We can use this equivalence and note that $B = P^\sigma \frac{E}{P}$, leaving $B = P^{\sigma-1}E$. Replacing E by Y yields the well-known formula. Note also that we can plug in $q_d(\phi) = \Delta(\sigma-1)B$ and $\tau q_x(\phi) = \Delta(\sigma-1)B\phi^\sigma\tau^{1-\sigma}$. Replacing these terms in the previous equations, we obtain: $l(\phi) = f_e + \mathbb{1}_d\left(\frac{q_d(\phi)}{\phi} + f\right) + \mathbb{1}_x\left(\tau\frac{q_x(\phi)}{\phi} + f_e\right)$. This gives us the correct formula. To prove the equivalence of the two results, recall that $\frac{p_{ij}(\phi)^{-\sigma}\tau_{ij}}{\phi} Y_j P_j^{\sigma-1}$. Notice that the terms $p_{ij}(\phi)^{-\sigma} Y_j P_j^{\sigma-1} = q_{ij}(\phi)$ so that we obtain: $\frac{q_{ij}(\phi)}{\phi}\tau_{ij}$, which can be interpreted as a composite of $l(\phi)$ where only τ for the domestic case is set to one. □

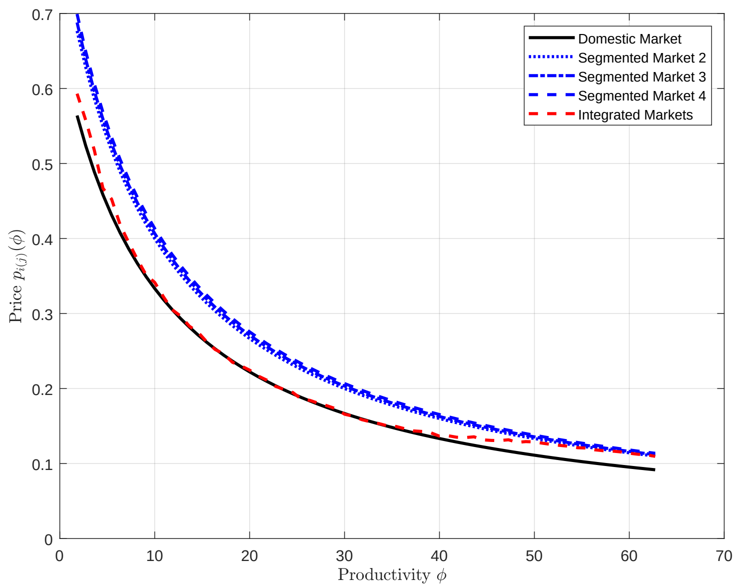
Appendix 3.B Visualization of model properties

Figure 3.8: Expected Aggregate Profits $\mathbb{E}_\epsilon(\Pi_i(\phi))$



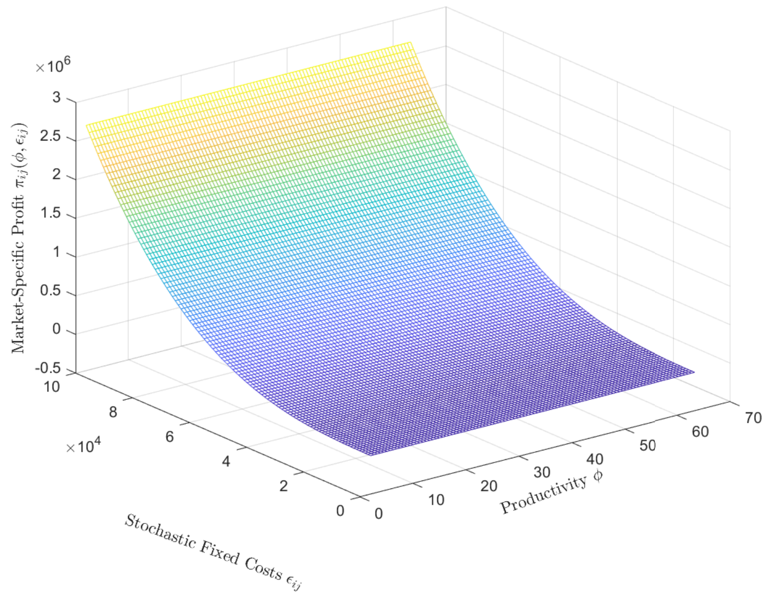
Notes: This figure displays the expected aggregate profits $\mathbb{E}_\epsilon(\Pi_i)$ for different trade cost levels τ_{ij} as a function of productivity ϕ.

Figure 3.9: Single-Pricing: A Weighted Mean



Notes: This figure shows integrated market pricing (blue lines) relative to segmented market pricing (red line). The scenario considers heterogeneous trade cost levels τ_{ij}.

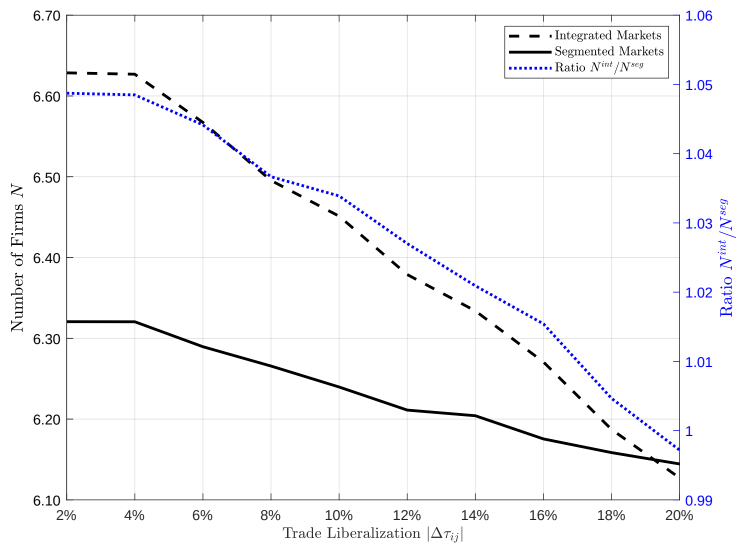
Figure 3.10: Bilateral Profits $\pi_{ij}(\phi, \epsilon_{ij})$



Notes: This figure displays the ex-ante bilateral profits $\pi_{ij}(\phi, \epsilon_{ij})$ as a function of the productivity level ϕ and the stochastic fixed costs ϵ_{ij} in equilibrium. Darker colors (blue) depict lower values.

Appendix 3.C Simulation results

Figure 3.11: Influencing Factor: Number of Firms



Notes: This figure displays the number of firms for segmented markets (black line), integrated markets (dashed black line) and the ratio N^{int}/N^{seg} (dotted blue line) across different trade cost reductions $|\Delta\tau_{ij}|$.

Table 3.7: Influencing Factor: Number of Firms N_i

	(a) N_i — Integrated markets across f_{ij} and J				
	$\|\Delta\tau_{ij}\| = 2\%$	$\|\Delta\tau_{ij}\| = 4\%$	$\|\Delta\tau_{ij}\| = 6\%$	$\|\Delta\tau_{ij}\| = 8\%$	$\|\Delta\tau_{ij}\| = 10\%$
$f_{ij} = 1e^1$	6.19	6.18	6.13	6.12	6.12
$f_{ij} = 1e^2$	6.57	6.52	6.45	6.40	6.33
$f_{ij} = 1e^3$	6.63	6.63	6.57	6.50	6.45
$f_{ij} = 1e^4$	6.45	6.44	6.44	6.45	6.44
$J = 2$	12.48	12.45	12.37	12.39	12.30
$J = 4$	6.63	6.63	6.57	6.50	6.45
$J = 6$	4.37	4.35	4.34	4.32	4.29
$J = 8$	3.30	3.28	3.26	3.25	3.24
$J = 10$	2.64	2.62	2.61	2.60	2.59
	(b) N_i — Segmented markets across f_{ij} and J				
$f_{ij} = 1e^1$	6.08	6.07	6.06	6.05	6.05
$f_{ij} = 1e^2$	6.14	6.14	6.14	6.13	6.13
$f_{ij} = 1e^3$	6.32	6.32	6.29	6.27	6.24
$f_{ij} = 1e^4$	6.37	6.37	6.36	6.35	6.37
$J = 2$	11.87	11.87	11.73	11.70	11.65
$J = 4$	6.32	6.32	6.29	6.27	6.24
$J = 6$	4.15	4.14	4.11	4.09	4.09
$J = 8$	3.12	3.10	3.09	3.09	3.06
$J = 10$	2.50	2.49	2.47	2.46	2.45

Notes: This table shows the number of firms for different scenarios. Panel (a) considers integrated markets and distinguishes different market entry costs f_{ij} and different numbers of markets. Panel (b) displays the respective results for segmented markets.

Table 3.8: Initial Welfare Levels

Scenario	**Wel**^{int}	**Wel**^{seg}
Baseline	5.633	5.673
	(a) Market entry costs f_{ij}	
$f_{ij} = 1e^1$	6.706	6.797
$f_{ij} = 1e^2$	6.193	6.277
$f_{ij} = 1e^3$	5.633	5.673
$f_{ij} = 1e^4$	5.177	5.186
	(b) Number of markets J	
$J = 2$	6.672	6.696
$J = 4$	5.633	5.673
$J = 6$	5.121	5.159
$J = 8$	4.794	4.833
$J = 10$	4.566	4.599

Notes: This table shows the initial welfare levels (i.e., $|\Delta\tau_{ij}| = 0\%$) for the baseline scenario, for different market entry costs f_{ij} (Panel (a)) and for different numbers of markets J (Panel (b)).

Table 3.9: Baseline: Welfare Changes for f_{ij}

	(a) Welfare changes — Integrated markets				
	$\lvert\Delta\tau_{ij}\rvert = 2\%$	$\lvert\Delta\tau_{ij}\rvert = 4\%$	$\lvert\Delta\tau_{ij}\rvert = 6\%$	$\lvert\Delta\tau_{ij}\rvert = 8\%$	$\lvert\Delta\tau_{ij}\rvert = 10\%$
$f_{ij} = 1e^1$	1.58%	3.16%	4.79%	6.47%	8.22%
$f_{ij} = 1e^2$	1.32%	2.70%	4.14%	5.64%	7.17%
$f_{ij} = 1e^3$	0.86%	1.77%	2.74%	3.79%	4.89%
$f_{ij} = 1e^4$	0.05%	0.09%	0.16%	0.25%	0.36%
	(b) Welfare changes — Segmented markets				
$f_{ij} = 1e^1$	1.24%	2.55%	3.94%	5.41%	6.97%
$f_{ij} = 1e^2$	1.06%	2.18%	3.37%	4.64%	5.99%
$f_{ij} = 1e^3$	0.73%	2.38%	3.31%	4.33%	5.43%
$f_{ij} = 1e^4$	0.04%	0.10%	0.16%	0.25%	0.35%

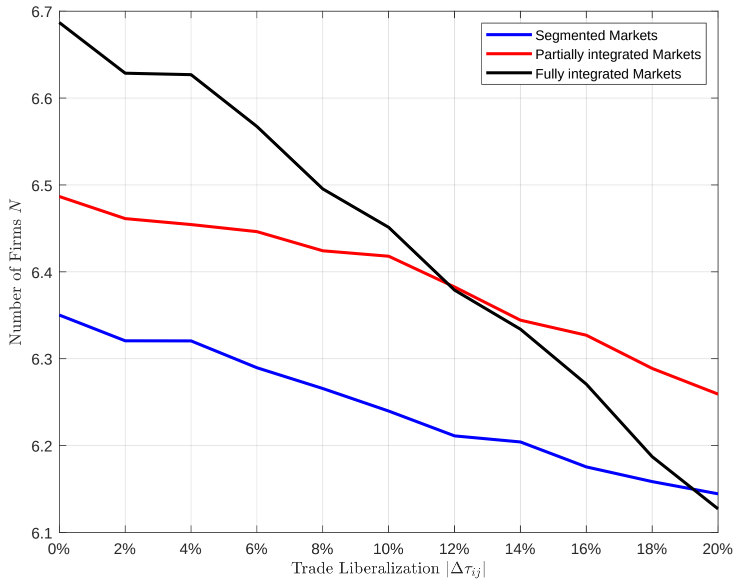
Notes: This table displays the welfare changes for different market entry costs f_{ij}. Panel (a) shows the results for integrated markets, Panel (b) for segmented markets.

Table 3.10: Baseline: Welfare Changes for J

	(a) Welfare changes — Integrated markets				
	$\lvert\Delta\tau_{ij}\rvert = 2\%$	$\lvert\Delta\tau_{ij}\rvert = 4\%$	$\lvert\Delta\tau_{ij}\rvert = 6\%$	$\lvert\Delta\tau_{ij}\rvert = 8\%$	$\lvert\Delta\tau_{ij}\rvert = 10\%$
$J = 2$	0.44%	0.91%	1.40%	1.93%	2.47%
$J = 4$	0.86%	1.77%	2.74%	3.79%	4.89%
$J = 6$	1.10%	2.26%	3.48%	4.78%	6.16%
$J = 8$	1.25%	2.58%	3.99%	5.47%	7.01%
$J = 10$	1.37%	2.78%	4.28%	5.87%	7.55%
	(b) Welfare changes — Segmented markets				
$J = 2$	0.34%	0.72%	1.13%	1.57%	2.07%
$J = 4$	0.73%	1.52%	2.38%	3.31%	4.33%
$J = 6$	0.98%	2.02%	3.12%	4.31%	5.59%
$J = 8$	1.11%	2.31%	3.60%	4.98%	6.43%
$J = 10$	1.24%	2.56%	3.95%	5.43%	7.03%

Notes: This table displays the welfare changes for different numbers of markets J. Panel (a) shows the results for integrated markets, Panel (b) shows the results for segmented markets.

Figure 3.12: Partial Integration: Number of firms



Notes: This figure displays the number of firms for partially integrated markets (red line), fully integrated markets (yellow line) and segmented markets (blue line) across different trade cost reductions $\lvert\Delta\tau_{ij}\rvert$.

Table 3.11: Extension: Welfare Changes for τ_{ij} and f_{ij}

	$\lvert\Delta\tau_{ij}\rvert = 2\%$	$\lvert\Delta\tau_{ij}\rvert = 4\%$	$\lvert\Delta\tau_{ij}\rvert = 6\%$	$\lvert\Delta\tau_{ij}\rvert = 8\%$	$\lvert\Delta\tau_{ij}\rvert = 10\%$
(a) Welfare changes — Integrated markets					
$\tau_{ij}^{het.}$	0.72%	1.69%	2.65%	3.60%	4.70%
$f_{ij}^{het.}$	1.45%	2.92%	4.48%	5.94%	7.45%
(b) Welfare changes — Segmented markets					
$\tau_{ij}^{het.}$	0.62%	1.37%	2.18%	3.00%	3.96%
$f_{ij}^{het.}$	1.16%	2.39%	3.65%	4.92%	6.26%

Notes: This table displays the welfare changes for heterogeneous trade cost levels τ_{ij} and fixed entry costs f_{ij}. Panel (a) shows the results for integrated markets, Panel (b) for segmented markets.

Table 3.12: Extension: Welfare Changes for L_i

	$\lvert\Delta\tau_{ij}\rvert = 2\%$	$\lvert\Delta\tau_{ij}\rvert = 4\%$	$\lvert\Delta\tau_{ij}\rvert = 6\%$	$\lvert\Delta\tau_{ij}\rvert = 8\%$	$\lvert\Delta\tau_{ij}\rvert = 10\%$
(a) Welfare changes — Integrated markets					
$L_i = 50$	1.21%	2.52%	3.87%	5.36%	7.06%
$L_i = 100$	0.87%	1.78%	2.73%	3.72%	4.80%
$L_i = 200$	0.48%	0.98%	1.58%	2.19%	2.80%
(b) Welfare changes — Segmented markets					
$L_i = 50$	1.10%	2.23%	3.47%	4.82%	6.31%
$L_i = 100$	0.70%	1.46%	2.30%	3.21%	4.20%
$L_i = 200$	0.40%	0.83%	1.29%	1.79%	2.33%

Notes: This table displays the welfare changes for heterogeneous market size L_i. Panel (a) shows the results for integrated markets, Panel (b) for segmented markets.

Table 3.13: Robustness: Shape Parameter α

	(a) Welfare changes — Integrated markets				
	$\lvert\Delta\tau_{ij}\rvert = 2\%$	$\lvert\Delta\tau_{ij}\rvert = 4\%$	$\lvert\Delta\tau_{ij}\rvert = 6\%$	$\lvert\Delta\tau_{ij}\rvert = 8\%$	$\lvert\Delta\tau_{ij}\rvert = 10\%$
$\alpha = 2$	0.87%	1.79%	2.79%	3.81%	4.90%
$\alpha = 3$	0.86%	1.77%	2.74%	3.79%	4.89%
$\alpha = 4$	0.88%	1.83%	2.84%	3.91%	5.06%
	(b) Welfare changes — Segmented markets				
$\alpha = 2$	0.78%	1.52%	2.37%	3.30%	4.30%
$\alpha = 3$	0.73%	1.52%	2.38%	3.31%	4.33%
$\alpha = 4$	0.75%	1.56%	2.44%	3.39%	4.43%

Notes: This table displays the welfare changes for different values of α. Panel (a) shows the results for integrated markets, Panel (b) for segmented markets. In each panel, we deviate from the main specification only in the respective dimension.

Table 3.14: Robustness: Shape Parameter β

	(a) Welfare changes — Integrated markets				
	$\lvert\Delta\tau_{ij}\rvert = 2\%$	$\lvert\Delta\tau_{ij}\rvert = 4\%$	$\lvert\Delta\tau_{ij}\rvert = 6\%$	$\lvert\Delta\tau_{ij}\rvert = 8\%$	$\lvert\Delta\tau_{ij}\rvert = 10\%$
$\beta = 2.5$	1.13%	2.30%	3.52%	4.81%	6.16%
$\beta = 3$	0.86%	1.77%	2.74%	3.79%	4.89%
$\beta = 3.5$	0.60%	1.23%	1.95%	2.72%	3.56%
	(b) Welfare changes — Segmented markets				
$\beta = 2.5$	0.95%	1.97%	3.05%	4.21%	5.46%
$\beta = 3$	0.73%	1.52%	2.38%	3.31%	4.33%
$\beta = 3.5$	0.51%	1.08%	1.70%	2.38%	3.14%

Notes: This table displays the welfare changes for different values of β. Panel (a) shows the results for integrated markets, Panel (b) for segmented markets. In each panel, we deviate from the main specification only in the respective dimension.

Table 3.15: Robustness: Location Parameter a

	(a) **Welfare changes — Integrated markets**				
	$\|\Delta\tau_{ij}\| = 2\%$	$\|\Delta\tau_{ij}\| = 4\%$	$\|\Delta\tau_{ij}\| = 6\%$	$\|\Delta\tau_{ij}\| = 8\%$	$\|\Delta\tau_{ij}\| = 10\%$
$a = 8$	0.82%	1.69%	2.62%	3.62%	4.69%
$a = 9$	0.85%	1.77%	2.75%	3.76%	4.82%
$a = 10$	0.86%	1.77%	2.74%	3.79%	4.89%
	(b) **Welfare changes — Segmented markets**				
$a = 8$	0.70%	1.46%	2.28%	3.18%	4.16%
$a = 9$	0.73%	1.52%	2.38%	3.30%	4.28%
$a = 10$	0.73%	1.52%	2.38%	3.31%	4.33%

Notes: This table displays the welfare changes for different values of a. Panel (a) shows the results for integrated markets, Panel (b) for segmented markets. In each panel, we deviate from the main specification only in the respective dimension.

Table 3.16: Robustness: Location Parameter b

	(a) **Welfare changes — Integrated markets**				
	$\|\Delta\tau_{ij}\| = 2\%$	$\|\Delta\tau_{ij}\| = 4\%$	$\|\Delta\tau_{ij}\| = 6\%$	$\|\Delta\tau_{ij}\| = 8\%$	$\|\Delta\tau_{ij}\| = 10\%$
$b = 1$	0.88%	1.76%	2.76%	3.84%	4.96%
$b = 2$	0.86%	1.77%	2.74%	3.79%	4.89%
$b = 3$	0.85%	1.73%	2.67%	3.67%	4.73%
	(b) **Welfare changes — Segmented markets**				
$b = 1$	0.73%	1.52%	2.38%	3.32%	4.34%
$b = 2$	0.73%	1.52%	2.38%	3.31%	4.33%
$b = 3$	0.73%	1.51%	2.36%	3.28%	4.27%

Notes: This table displays the welfare changes for different values of b. Panel (a) shows the results for integrated markets, Panel (b) for segmented markets. In each panel, we deviate from the main specification only in the respective dimension.

4 Innovation of Heterogeneous Firms with Interdependent Market Entry

Abstract

In this paper, we build a heterogeneous firm model in which firms innovate by choosing one optimal investment level to lower marginal production costs by raising their effective productivity. Since this choice depends on all export choices, market-entry for one market depends on market-entry towards other markets, and is hence, interdependent. Stochastic fixed costs transform the export choice into a probabilistic notion, leading to a continuous objective function with well-defined optimality conditions. We find higher welfare levels for market integration relative to a benchmark scenario with market-specific investments. Intuitively, the aggregate investment level is higher than the market-specific investment, which also leads to higher welfare gains when liberalizing trade. The gains are increasing in the number of destinations and a decreasing function of investment returns in both scenarios.

4.1 Introduction

There is strong empirical evidence that exporting firms are more productive, more innovative, more capital intensive and larger in size than non-exporting firms (Bernard and Jensen, 1997; Aw et al., 2007, 2008; Bustos, 2011; Lileeva and Trefler, 2010).[1] Related literature debates whether larger ex-ante productivity levels create incentives for firms to self-select into exporting (Bustos, 2011; Aw et al., 2007, 2008), or if alternatively, exporting to foreign markets leads to learning effects, which positively influence firm productivity (Baldwin and Gu, 2003). While there is evidence for both scenarios, the recent literature suggests models in which firms raise productivity by adopting more advanced technologies (Atkeson and Burstein, 2010; Costantini and Melitz, 2007). Frequently, the literature assumes two-country setups, thus distinguishing between a foreign and the domestic country and ignoring that technology adoption creates market interdependence in the presence of multiple countries.

We provide a multi-country setting with a joint productivity-export decision that creates an interaction between markets. The idea is that firms hire researchers to lower their marginal production costs. Importantly, the optimal investment choice is not market-specific, but the additional labor affects the productivity level with which firms serve all of their destination markets. As a consequence, the optimal investment, as well as the export choice for one market, depend on the firm's market entry choice with respect to all (other) markets.

To better understand the intuition, consider the following example. An innovative firm such as Volkswagen (VW) faces the following two decisions. First and based on its actual profits, VW makes export decisions for all potential markets, for example, the markets in the United States and China. Second, based on its expected aggregate profits, VW sets the innovation budget to increase the market shares and compete against incumbent firms in all markets. In this example, the investment choice takes into account VW's future expected profits in all markets, including the profits in the United States. The higher productivity, however, affects the expected profits

[1] For instance, even in trading sectors not all firms export, and in addition, the productivity level is higher among exporting than non-exporting firms in a non-tradable sector (e.g., Bernard and Jensen, 1995, 1999, 2004b,a, Clerides et al., 1998, Aw et al., 2000 and Eaton et al., 2004).

in other markets as well, e.g., in China, and therefore influences whether VW serves the Chinese market. This depicts the idea of market interdependence clearly and creates a setting that allows us to determine how an integrated market structure affects firms in their individual choices as well as the economy in terms of aggregate welfare.

To formalize market interdependence, we extend a heterogeneous firm model in the tradition of Melitz (2003) by introducing a continuous investment choice that allows heterogeneous firms to increase their effective productivity. Effective productivity is a compound of the firm's ex-ante productivity level, and the innovation choice, which lowers marginal costs and enables firms to charge lower prices. The investment choice is hence a function of the firm's market entry choice with respect to all markets, and in turn, influences the firm's export choice for all markets.

We model innovation in terms of labor and the respective wage level. Specifically, firms hire κ researchers based on the firm's expected aggregate profits, which depend on the firm's initial productivity but also the market income, bilateral trade costs, and the export choice towards all markets. We assume positive investment returns, which we capture by a non-negative scaling parameter (γ) for investment. The restriction that $\gamma < 1$ ensures decreasing returns to scale. The edge knife case ($\gamma = 0$) characterizes a state of the world in which there are no investment returns leaving productivity at its ex-ante level.

Second, we introduce stochastic market entry costs to relax the common two-country assumption and obtain a well-defined objective function without discontinuities.[2] The underlying idea is straightforward. Market interdependence implies that innovation is a function of market entry, which is typically binary, i.e., firms either export or not. For a larger number of destination markets (J), this requires a comparison of 2^J different combinations to identify the optimal export choice per firm. The advantage of stochastic fixed costs is that it transforms the market entry into a probabilistic choice resulting in a well-defined objective function for which first-order conditions exist. Also, by the law of large numbers, this constitutes the fraction of firms that serve foreign markets. To enter market j, firms pay market entry costs, which consist of a deterministic part and the market-specific draw of the stochastic component. This modeling device implies that every firm can serve an export market if the fixed costs are sufficiently low. Market-specific prices are chosen before the stochastic fixed costs become known to the firm to ensure that market entry remains probabilistic.

We use this model to evaluate how market integration affects aggregate welfare by linking the welfare effects back to the firm-specific investment-, exporting-, and pricing decisions. In our baseline scenario, there are no domestic trade frictions, while we assume symmetric bilateral trade costs of 20%. Starting from this equilibrium, we consider an exogenous trade cost decline of 10% and calculate the welfare changes. The main finding of our empirical exercise is that trade liberalization leads to higher welfare gains for integrated markets than in a setting with market-specific investments and segmented markets. The results crucially depend on the investment returns, which scale the respective technology choice and the number of markets.

For positive returns, we find higher welfare levels and gains for integrated markets. In the baseline case with $J = 4$ and $\gamma \in \{0.20, ..., 0.30\}$, the gains from a 10% decline in bilateral trade costs are between 1.55% and 1.59% for integrated markets, and between 1.05% and 1.09% for segmented markets. Despite higher aggregate investments under segmentation, the technology adopted by every market is higher for market integration. In both settings, the welfare gains are increasing in the number of markets and decreasing in the investment returns. The first argument is as follows: An increasing number of markets lowers the own market size and forces firms to pay more market entry costs. A reduction in trade costs leads to lower frictions, letting firms benefit from more markets. The second finding is the result of a level effect because, for constant trade costs, technology adoption raises welfare by more than the reduction in trade costs. Since the aggregate implications closely relate to the firm-specific effects, we proceed in

[2] In a recent study, Antràs et al. (2017) allow for interdependent market entry in a global sourcing framework by applying a solution mechanism introduced by Jia (2008). However, the solution mechanism is only applicable to a constraint set of parameter values.

two steps.

First, we evaluate how different investment returns affect firms in their choices to innovate, to choose optimal price levels, and to serve foreign markets. Overall, we find a positive relationship between the returns and the optimal investment level. This leads to lower production costs, which imply that firms charge lower price levels, are more likely to export, and have larger sales shares at the expense of low-productivity firms. The larger sales share indicates a shift in the resources from low- to high-productivity firms. Our findings are the combination of a decline in marginal production costs and a rise in effective productivity. The assumption of decreasing investment returns, however, may affect the pattern when investment returns are too large, which lowers the optimal investment level but does not affect our welfare findings. Further, we find that the number of firms is decreasing in equilibrium as a result of selection: the larger the optimal technology adoption, the higher is the resulting demand for labor. Given its fixed supply, the subsequent rise in real wages increases inequality in profits because the least productive firms are forced to leave the export market.

In a second exercise, we evaluate how the total number of markets (J) influences individual firms. The combination of a constant aggregate labor force and an increasing number of markets imposes the following trade-off: On the one hand, the labor force per market is lower, and beyond that, firms must pay market entry costs for a larger number of markets. Both effects negatively influence the export probability for a given market. On the other hand, firms can gain larger market shares conditional on exporting when potential competitors are not productive enough to cover the market-specific entry costs. Further, a reduction in trade costs enables firms to serve more markets at once. Our results confirm the relevance of the aggregate market size as stressed by Schmookler (1954) and Lileeva and Trefler (2010). To be more precise, an increasing number of markets leads to a lower optimal innovation level and market entry probability. On the contrary, optimal pricing-to-market is an increasing function of J. The relevance of these two firm-specific findings closely relate to the welfare analysis showing that the presence of market interdependence does not only affect firm-specific behavior but also aggregate welfare.

Related Literature

Our paper adds to various strands of literature. We first contribute to the empirical literature on the positive correlation between the export choice and 'research and development' (R&D) investment. While some studies highlight the self-selection effect of more productive firms into exporting (Bernard and Jensen, 1997; Aw et al., 2007, 2008; Altomonte et al., 2013; Damijan et al., 2017; Aghion et al., 2018; Lileeva and Trefler, 2010), other studies find evidence for the learning-by-exporting hypothesis (Baldwin and Hanel, 2003; Baldwin and Gu, 2004; Cassiman and Golovko, 2011). They argue that innovation by firms does not only depend on R&D, but also on ideas and technology from various other sources, both internal and external to the firm. We structurally estimate an extended version of the heterogeneous firm model which makes no prediction on timing but allows for self-selection and technology investments.

Our work also relates to research by Yeaple (2005), Bustos (2011) and Costantini and Melitz (2007) who explicitly model technology adoption following trade liberalization scenarios in a binary choice setting. Specifically, Bustos (2011) and Lileeva and Trefler (2010) find that the market entry induced by foreign trade liberalization stimulates the adoption of new technologies. Extensions by Atkeson and Burstein (2010) and Aw et al. (2011) consider model structures which explicitly capture the channel of trade liberalization on the R&D investment and thus, on the endogenous development of productivity in a dynamic framework.[3] In contrast, we consider a static setting, in which firms make a joint export-investment choice for more than two markets. Since the productivity decision affects the production efficiency of firms for all markets, the

[3] The export decision has also been linked to firms' capital investment (Wacziarg, 2001), the diffusion in technology (Sampson, 2016), export-learning effects (Albornoz et al., 2012; Egger et al., 2011) and greater investment in R&D (Bloom et al., 2015; Keller, 1998, 2002).

investment choice depends on characteristics from all markets as well, including the market entry choice. We thus contribute to a literature which shows that trade liberalization has a substantial influence on the individual firm's decision to export and invest in R&D, both to improve the quality of existing products and to create new products (see Lileeva and Trefler, 2010; De Loecker, 2007).

We also contribute to a strand of literature that models interdependent market entry and presents suitable solution mechanisms. In particular, Yeaple (2003) and Grossman et al. (2006) describe the inherent difficulties in solving for the extensive margin of imports in a multi-country model with multiple intermediate inputs and heterogeneous fixed costs of sourcing. Jia (2008) provides a solution mechanism for integrated markets which Antràs et al. (2017) use in the global sourcing context. However, their solution is restricted in the range of parameter values. Finally, our work also adds to the literature highlighting the importance of fixed costs for the extensive margin of exports (Eaton et al., 2004, 2011). Arkolakis (2010) argues that the fixed costs of serving a market depend on the endogenous fraction of consumers that firms choose to serve. We extend market-specific fixed costs by a stochastic component.

Structure. In the remainder of the paper, Section 4.2 reviews the sources of technology growth and provides descriptive evidence. Section 4.3 provides a detailed exposition of the model. Section 4.4 describes the calibration procedure and Section 4.5 presents the simulation results. Sections 4.6 and 4.7 provide sensitivity results and concluding remarks.

4.2 Institutional background on technology investment

The 'Organisation for Economic Co-operation and Development' (OECD) defines productivity as the ratio between output and inputs and captures the degree of efficiency with which input factors such as labor and capital produce a given amount of output. While this definition is very general, recent literature has considered productivity at the firm-level. For example, Melitz and Redding (2014) define productivity as the degree of heterogeneity in revenue based on differences in factor inputs across firms, including differences in technical efficiency, firm structures, and organization units as well as product quality.

Given the heterogeneity in productivity, firms aim to raise their productivity by making related investments and to increase their profit and market share. In this paper, we use the terms innovation, technology adoption, and productivity improvement interchangeably. While a broad definition of technology investments includes spending on computers, software, technology transfers, and innovation activities performed within firms like research and development (Bustos, 2011), we emphasize improvements in the single input factor labor. For each firm, there are two opposing rationales. For one, innovation is costly and leads to a free-rider problem, given the non-exclusive usage of technology. On the other hand, higher productivity levels drive down marginal production costs and increase both revenues and profits.

According to Arora et al. (2017), firms invest on their own instead of free-riding to absorb external knowledge, which is more fruitful when being more productive. Second, innovative firms have a reputation with consumers and in the race to attract specialized labor and investors (see also Audretsch and Stephan, 1996). In the following, we briefly review the mechanisms of firm-specific innovation and provide descriptive evidence based on the firm-specific heterogeneity in R&D, related expenditures using descriptive firm-level data from the United States (US).

4.2.1 Export, R&D and productivity

To understand how firms raise individual and aggregate productivity, we briefly disentangle the relationship between the initial productivity, a firm's export decision, and its productivity choice. Export decisions and investment choices (e.g., by investing in product innovation) are complementary for productivity growth (Lileeva and Trefler, 2010). This is important in the context of trade liberalization because improved access to foreign markets encourages firms to serve export markets and innovate (Grossman and Helpman, 1995; Lileeva and Trefler, 2010).

Starting with the canonical model by Melitz (2003), even though ex-ante productivity levels are constant, opening foreign markets to domestic firms positively affects aggregate productivity, which is due to the so-called 'self-selection channel'. In its simplest form, more productive firms have higher revenues and constitute the set of firms that pay the export fixed costs. This mechanism positively affects the average productivity of the remaining firms. Formally, firms with productivity levels $\phi < \phi^*$, where ϕ^* denotes the cutoff productivity for exporting, leave the market. Trade liberalization can increase aggregate productivity by inducing a better allocation of production factors (Pavcnik, 2002; Melitz, 2003; Bernard et al., 2003). A similar argument is by Schmookler (1954), who argues that the profitability of productivity investments are increasing in the effective market size.

Second, Cassiman and Golovko (2011) go a step further to explore which factors enable more productive firms to gain productivity advantages. A starting point is to interpret the positive correlation between productivity and the export choice as a learning-by-exporting effect, meaning that entering foreign markets allows gaining knowledge and expertise, which all lead to an improvement in the production efficiency (De Loecker, 2007). Similarly, more competitive market environments may force firms to raise their efficiency, similar to establishing contact with foreign competitors and consumers. Baldwin and Hanel (2003) present evidence based on this channel for Canadian manufacturing firms, finding that once firms participate in the export market, they improve their productivity with the learning process building on existing plant capabilities.[4]

Finally, firms undertake investments in research and development to raise productivity and their export probability. Facing innovation costs, firms only invest in R&D when the present discount for profits is higher than the investment costs (e.g., Aw et al., 2008, 2011). In this context, the payoff from innovation is affected by the firm's export status since firms serving some foreign markets may be able to benefit from a new product or improved production process more than firms serving only the domestic market (Baldwin and Gu, 2004; Peters et al., 2016). Differences in expected returns from R&D investment and similarly, different levels of optimal R&D investments affect the productivity growth for domestic and exporting firms.

In its simplest form, firms can update their technology level and reduce their marginal cost of production by paying additional fixed costs. Using this framework, Bustos (2011) finds a composite effect of better-allocating production factors, adopting more advanced technologies. Her work is inspired by Yeaple (2005), who finds an inverse relationship between the trade costs and the share of firms that use more advanced technologies. The rationale is intuitive. Given the joint treatment of export and technology investment, high-productivity firms have higher revenues when trade costs decline and can, therefore, cover the fixed costs to adopt technology and to enter the export market. This leads to a disproportionate rise in revenues and profits. Yet, the model only allows firms to choose between two states of technology, rather than choose a continuous investment level. As a result, the sorting of firms is such that only exporting firms consider using more advanced technologies.

Apart from the importance of the export status, there is also path dependence on the initial level of firm productivity, implying that more productive firms invest more in R&D than less productive firms. This serves as an additional selection criterion (Aw et al., 2011). Aghion et al. (2018) emphasize two conflicting channels. For one, there is a direct 'market size effect' stating that an increase in market size rises the optimal innovation level because the innovation rents come from a larger market. On the other hand, there is a 'competition effect' stemming from the increased incentives for additional firms to enter the (new) markets. This setup leads to a heterogeneous innovation outcome for an identical market size shock across firms, with the most

[4] Evidence of Sub-Saharan firms comes from Van Biesebroeck (2005), while Salomon and Shaver (2005) show that Spanish firms are more likely to make patent applications after entering the export markets.

productive firms having higher innovation levels than firms further distant to the productivity frontier.

Given the theoretical background, we briefly review descriptive evidence to highlight the heterogeneity of firms with respect to R&D investment and R&D employment.

4.2.2 Descriptive evidence on firm-heterogeneity in R&D investment

We now employ data from the 'Business Research and Development and Innovation Survey (BRDIS)'[5] to provide descriptive evidence on the R&D performance. We show that firms differ in terms of overall R&D investment, R&D intensity and highlight the role of firm heterogeneity.

Table 4.1 displays the overall R&D funds and R&D intensities for US companies in the period between 2003 and 2007. Panel (a) shows that medium and large companies with more than 500 employees have invested between 154.855 billion US$ in 2003 and 182.650 billion US$ in 2007. For smaller firms with less than 500 employees, the respective range is between 33.788 billion US$ and 42.078 billion US$. This pattern is not surprising since larger firms tend to be more productive and have larger research departments than small firms (Bernard et al., 2007b). To evaluate the success of R&D investment, Panel (b) of Table 4.1 displays the R&D intensity defined as the ratio of R&D expenditures and the reported sales revenues. With this exercise, we evaluate the extent to which firms spend their sales revenues on R&D activities. The data show that across all companies, the R&D intensity remains rather stable with 3.50% in 2003 and 3.80% in 2007. Small companies (less than 500 employees) have spent 3.10% of company sales revenues on R&D activities in 2003, 7.40% in 2005, and 8.60% in 2007. Medium and large companies have spent about 3.40% of their company revenues on R&D over the same period.

Table 4.1: R&D Funds and Intensities for Companies in the US

Company size (# of employees)	2003	2004	2005	2006	2007
	(a) R&D Funds ($, billions, 2000)				
All companies	188.643	190.295	200.081	212.271	224.728
Small companies (< 500)	33.788	34.791	35.813	38.756	42.078
Medium-large companies (≥ 500)	154.855	155.504	164.267	173.515	182.650
	(b) R&D Intensity (%)				
All companies	3.50	3.70	3.70	3.70	3.80
Small companies (< 500)	3.10	6.40	7.40	8.50	8.60
Medium-large companies (≥ 500)	3.60	3.40	3.30	3.30	3.40

Notes: This table displays the R&D funds and the R&D intensity for companies performing industrial R&D in the US, by company size. R&D intensity is defined as the ratio of R&D (in current US$) and R&D performing companies' reported sales revenues. Source: National Science Foundation (2007).

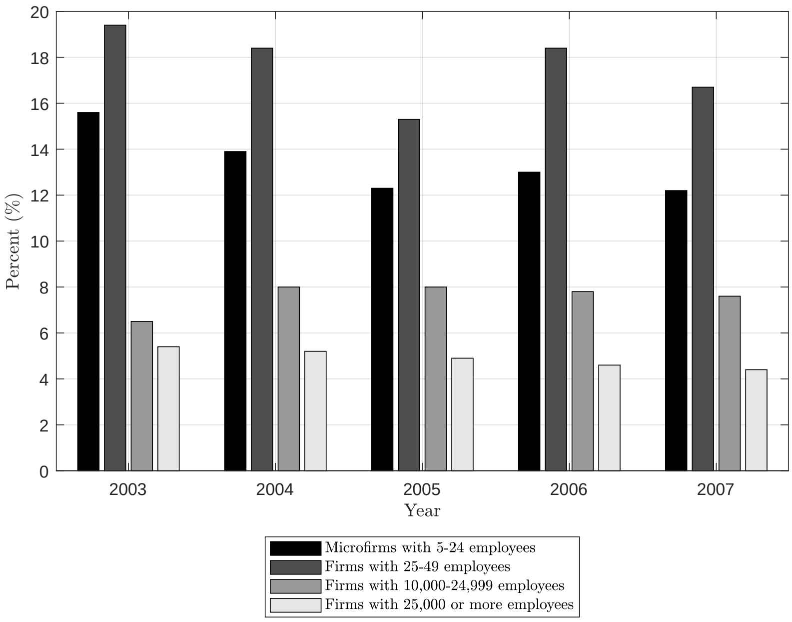
An additional measure is R&D employment, i.e., scientists and engineers employed by R&D related firms in the US. It is measured as the percentage of overall employment in the firms between 2003 and 2007. Figure 4.1 displays the results. R&D scientists and engineers accounted for 27.40% of total employment at R&D-performing microfirms on average during 2003−07 and 17.60% of total employment at US companies with 25−49 employees. In the two largest company size categories, R&D scientists and engineers accounted for 7.60% of total employment in firms with 10,000−24,999 employees and 4.90% of total employment at firms with 25,000 or

[5]The annual survey of Industrial Research and Development examines a nationally representative sample of companies in Manufacturing and non-Manufacturing industries.

more employees. The descriptive data show how firms differ in terms of investment and the respective labor force. It could either be the result of increased R&D investment or follow from declining sales with the same effect. The numbers show that both large and small firms have invested substantial amounts in R&D. Yet in absolute terms, large firms dominate.

Summary. The previously reviewed research has reached a consensus that R&D, productivity, and exporting are very closely related and need to be analyzed as a unit in the presence of firm heterogeneity. Our descriptive evidence confirms the importance of heterogeneity in the firm context. Yet, the existing literature misses considering multi-country setups with interdependent market entry, i.e., the connectivity of markets via an investment choice affecting the firm in all markets. The following section presents a model that delivers a suitable approach.

Figure 4.1: R&D Employment as % of Overall Employment, US (2003−2007)



Notes: This figure displays R&D-related scientists and engineers employed by R&D performing firms in the US (in percent of employment) between 2003−07, by company size. Source: National Science Foundation (2007).

4.3 A heterogeneous firm model with technology upgrade

We develop a multi-country extension of a heterogeneous firm model with innovation. Consider an economy with J countries (indexed by i, j) and a variety of output goods (indexed by ω). Firms are characterized by their productivity level (ϕ). Production takes place under conditions of increasing returns to scale and monopolistic competition. Every country is populated by a mass of L_i immobile workers who supply their labor inelastically. In country i, there are N_i heterogeneous firms that optimize expected aggregate profits by hiring $\kappa_i(\phi)$ researchers at wage rate w_i to improve technology and lower the marginal production costs. Figure 4.7 (see Appendix 4.A for details) presents a schematic overview on the order of events.

4.3.1 Preferences

In every country j, households derive their utility from the consumption of a differentiated good ω according to symmetric 'Constant Elasticity of Substitution' (CES) preferences (Antràs et al., 2017). Every consumer maximizes her utility by selecting consumption goods ω according to

$$U_j = \left(\sum_{i \in J} \int_{\Omega_{ij}} q_{ij}(\omega)^{\frac{\sigma-1}{\sigma}} d\omega \right)^{\frac{\sigma}{\sigma-1}} \text{ subject to } \quad \sum_{i \in J} \int_{\Omega_{ij}} p_{ij}(\omega) q_{ij}(\omega) d\omega = w_j L_j, \tag{1}$$

where $\sigma = 1/(1-\rho) > 1$ denotes the elasticity of substitution, $q_{ij}(\omega)$ represents the consumption level of variety ω produced in country i and consumed in country j. Ω_{ij} defines the set of goods from market i available in market j. The household's optimal demand for good ω is given by

$$q_{ij}(\omega) = \frac{p_{ij}(\omega)^{-\sigma}}{P_j^{1-\sigma}} L_j w_j, \tag{2}$$

where $p_{ij}(\omega)$ is the consumer price for variety ω, $w_j L_j$ defines the households' income Y_j, and P_j defines the composite CES price index of country j. It is given by

$$P_j \equiv \left(\sum_{i \in J} \int_{\Omega_{ij}} p_{ij}(\omega)^{1-\sigma} d\omega \right)^{\frac{1}{1-\sigma}}. \tag{3}$$

4.3.2 Production technologies

A mass of N_i firms in every region i produces a distinct variety of goods with increasing returns to scale production. Every firm has a blueprint in producing a unique variety ω.

Productivity. In any country i, firms differ across their productivity level ϕ. To learn their productivity level, firms participate in a lottery at cost $w_i f_i^e$ and draw their productivity from a Pareto distribution (Helpman et al., 2004; Chaney, 2008; Arkolakis et al., 2008, 2012)

$$f(\phi) = \beta b^\beta \phi^{-(\beta+1)}, \qquad F(\phi) = 1 - \left(\frac{b}{\phi}\right)^\beta \tag{4}$$

with support $[\underline{\phi}, \infty)$, location parameter $b > 0$ and shape parameter $\beta > 0$. Note that the shape parameter β captures the heterogeneity of draws across firms in all countries. The distribution is common for all markets and public information.

Stochastic fixed costs. A methodological novelty in our model is the assumption of stochastic fixed costs.[6] It allows us to consider an arbitrary number of markets because we circumvent the binary market entry choice, i.e., firms either export or not. This standard case would require to compare 2^J cases when determining the optimal firm structure and lead to numerical problems when the number of markets is large. Instead, we use stochastic fixed costs to obtain a continuous and well-defined objective function. Market entry is no longer binary but reflects the probability χ_{ij} of firm ϕ to serve market j. To achieve this, every firm experiences idiosyncratic shocks $\epsilon_{ij} \in [1;\infty)$, where the idiosyncratic part of the fixed costs follows a Pareto distribution $g(\epsilon)$ with location parameter a and shape parameter α such that the term $1/\epsilon_{ij}$ is bounded by the interval $(0, 1]$.

4.3.3 Profits and technology

Each firm faces two optimization problems, with the first involving the choice of market-specific prices $p_{ij}(\phi)$, while the second optimization problem is twofold and involves optimizing the number of export markets via the choice of technology. Firms can update their technology by hiring $\kappa_i(\phi)$ researchers at price w_i, which magnifies productivity by the factor $(1+\kappa_i(\phi))^{\gamma/(1-\sigma)}$.

[6] Firms hire a local expert for each market at the local wage rate (Egger and Kreickemeier, 2012).

Profit optimization. After observing their productivity level ϕ, firms maximize

$$\pi_{ij}(\phi) = \left[p_{ij}(\phi)^{1-\sigma} - \frac{w_i \tau_{ij}}{(1+\kappa_i(\phi))^{\frac{\gamma}{\sigma-1}} \phi} p_{ij}(\phi)^{-\sigma} \right] Y_j P_j^{\sigma-1} - \frac{1}{\epsilon_{ij}} w_i f_{ij}. \tag{5}$$

Optimization yields prices as a constant markup over marginal costs, i.e.,

$$p_{ij}(\phi) = \frac{\sigma}{\sigma-1} \frac{w_i \tau_{ij}}{\phi} (1+\kappa_i(\phi))^{\frac{\gamma}{1-\sigma}} . \tag{6}$$

The parameter γ, for which we impose $0 \leq \gamma < 1$, serves as a scaling factor of the investment choice. The assumption of decreasing returns to scale is necessary to bound the optimal technology level. For values $\sigma > 0$, marginal production costs are decreasing in the investment κ_i, which lowers the price level (p_{ij}). Upon the realization of stochastic fixed costs ϵ_{ij}, firms are not allowed to adjust their pricing rule (see Figure 4.7 in Appendix 4.A for details on the structure of events) because otherwise the export choice would become binary and the related objective function non-continuous. The market-specific profit function is then given by

$$\pi_{ij}(\phi) = \frac{1}{\sigma} \left(\frac{\sigma}{\sigma-1} \frac{w_i \tau_{ij}}{\phi} \right)^{1-\sigma} (1+\kappa_i(\phi))^{\gamma} Y_j P_j^{\sigma-1} - \frac{1}{\epsilon_{ij}} w_i f_{ij}. \tag{7}$$

Given the bilateral profit function, we next characterize the market-specific export choice of firm ϕ. The stochastic representation of fixed costs allows every firm to serve market j conditional on having sufficiently large realization of the idiosyncratic component. To streamline notation, we collect terms and define

$$V_{ij}^*(\kappa_i(\phi)) \equiv \frac{1}{\sigma} \left(\frac{\sigma}{\sigma-1} \frac{w_i \tau_{ij}}{(1+\kappa_i(\phi))^{\frac{\gamma}{\sigma-1}} \phi} \right)^{1-\sigma} \frac{Y_j P_j^{\sigma-1}}{w_i f_{ij}}. \tag{8}$$

It is immediate that firm ϕ will export to market j if the bilateral profits are non-negative, i.e. $\pi_{ij} \geq 0$. This imposes the following lower bound for the stochastic fixed costs ϵ_{ij}:

$$\epsilon_{ij} \geq \frac{1}{V_{ij}^*(\kappa_i(\phi))} \tag{9}$$

We can thus approximate the export probability $\chi_{ij}(\phi)$ by evaluating the cumulative distribution function at $1/V_{ij}^*(\kappa_i(\phi))$. Then, the probability function depends on the shape parameter α, i.e.,

$$\Pr(\epsilon_{ij} \geq \epsilon^*) = F\left(\frac{1}{V_{ij}^*(\kappa_i(\phi))} \right) = a^{\alpha} \left[V_{ij}^*(\kappa_i(\phi)) \right]^{\alpha} = \chi_{ij}(\phi). \tag{10}$$

Contrary to Melitz (2003), the stochastic nature of market entry costs alters the interpretation of an exporting firm. Instead of the binary choice, the market entry probability is bounded in the interval [0,1] — conditional on the realization ϵ_{ij}.[7] By the law of large numbers, the probability of serving market j is equivalent to the share of firms that serve the market. Trade between any regions i and j is costly. Trade costs $\tau_{ij} \geq 1$ are of the iceberg type. Hence, $\tau_{ij} \geq 1$ units of a good ω must be shipped from location i to location j for one unit to arrive.

Optimal technology choice. Every firm chooses its optimal investment level by maximizing the expected aggregate profits weighted by market entry probabilities and subject to investment

[7] The restriction $f_{ij} > f_{ii}$ $\forall j \in J$ ensures that exporting firms always serve the domestic market.

costs. Formally,

$$\mathbb{E}_{\epsilon}[\Pi_i(\phi)] = \left\{ \sum_j \chi_{ij}(\phi)\pi_{ij}(\phi) \right\} - \eta_i \kappa_i(\phi) w_i, \tag{11}$$

where $\eta_i > 0$ denotes the inverse efficiency level of technology, and $\chi_{ij}(\phi)$ determines the probability of firm ϕ to serve market j. In the following, we abbreviate $V_{ij}^*(\kappa_i(\phi))$ by V_{ij}^*. A positive investment affects the expected profits via lower optimal prices and a higher export probability. Plugging in the respective terms for the export probability $\chi_{ij}(\phi)$, and the optimal price $p_{ij}(\phi)$ leads to the following expression for aggregate expected profits conditional on exporting:

$$\mathbb{E}_{\epsilon}\left[\Pi_i(\kappa_i(\phi))\right] = \sum_j \left[\frac{1}{1+\alpha}\right] \chi_{ij}(\phi) V_{ij}^* w_i f_{ij} - \eta_i \kappa_i(\phi) w_i \tag{12}$$

The objective function specified above is well-defined without discontinuities (see Appendix 4.A for details), which implies the following first-order condition for technology adoption:

$$\kappa_i^*(\phi) = \frac{\gamma}{\eta_i} \sum_j \chi_{ij}(\phi) V_{ij}^* f_{ij} \tag{13}$$

The chosen investment level is a positive function of the investment returns (γ), the export probability (χ_{ij}), and the term V_{ij} which is, e.g., increasing in income (Y_j) and decreasing in the price level (p_{ij}). On the other hand, the optimal κ is inversely related to the inefficiency parameter (η_i.) To illustrate the link between the share of exporting firms and their productivity, we impose the zero profit cutoff condition, which leads to the expression

$$\pi_{ij}(\phi^*) = V_{ij}^* w_i f_{ij} - \left(\frac{1}{V_{ij}^*}\right)^{-1} w_i f_{ij} = 0. \tag{14}$$

Importantly, both ϕ and ϵ_{ij} determine market j's profits, so that the marginal firm is determined by a combination of both random variables. As a result of the law of large numbers, for each productivity level exists a share of firms that draw a sufficiently low ϵ_{ij} to serve that market.

Free market entry. In the aggregate economy, free entry requires zero expected profits in equilibrium. Positive profits would lead to additional firm entry and drive profits to zero. This implies that total revenues from all markets must be equal to the participation costs $w_i f_i^e$ ('lottery costs') and the costs of investing in additional technology, $\eta_i \kappa_i^*(\phi) w_i$. Formally,

$$\mathbb{E}_{\phi}(\Pi_i(\phi)) = \left(\frac{1}{\alpha+1}\right) \int_{\Phi} \left(\left[\sum_j \chi_{ij}(\phi) V_{ij}^* w_i f_{ij} \right] - \eta_i \kappa_i(\phi) w_i \right) f(\phi) d\phi \stackrel{!}{=} w_i f_i^e. \tag{15}$$

Labor markets. On the country level, labor market clearing requires that labor supply match labor demand. Labor is used to cover the participation investment (f_i^e) and market-specific fixed costs (f_{ij}). Besides, firms employ labor to adopt technology use it as the only input factor in goods production. This leads to the following labor market clearing condition:

$$\begin{aligned} L_i = {} & N_i f_i^e + N_i \sum_j \int_{\underline{\phi}_i}^{\infty} \chi_{ij}(\phi) \frac{p_{ij}(\phi)^{-\sigma} \tau_{ij}}{(1+\kappa_i(\phi))^{\frac{\gamma}{\sigma-1}} \phi} Y_j P_j^{\sigma-1} f(\phi) d\phi + N_i \eta_i \int_{\underline{\phi}_i} \kappa_i(\phi) f(\phi) d\phi \\ & + N_i \sum_j \int_{\underline{\phi}_i}^{\infty} \chi_{ij}(\phi) f_{ij} f(\phi) d\phi, \end{aligned} \tag{16}$$

where N_i denotes the number of firms located in country i and $\delta \equiv (1+\kappa_i(\phi))^{\frac{\gamma}{\sigma-1}}$. The effective productivity of $\delta\phi$ is also determined by the number of markets served by firms producing in country i. Further, we can pin down the number of firms by rearranging terms:

$$N_i = \frac{L_i}{f_i^e + \sum_j \int_{\underline{\phi}_i}^{\infty} \chi_{ij}(\phi) \frac{p_{ij}(\phi)^{-\sigma}\tau_{ij}}{(1+\kappa_i(\phi))^{\frac{\gamma}{\sigma-1}}\phi} Y_j P_j^{\sigma-1} f(\phi)d\phi + \sum_j \int_{\underline{\phi}_i}^{\infty} \chi_{ij}(\phi) f_{ij} f(\phi)d\phi + \eta_i \int_{\underline{\phi}_i} \kappa_i(\phi) f(\phi)d\phi} \tag{17}$$

According to equation (17), adopting more advanced technologies influences the number of firms using three channels. First, higher investments lower marginal production costs as well as optimal price levels, leading to an increase in the number of firms. Second, high-productivity firms with positive investment levels are more likely to export, which increases labor demand, and as a result, leads to a dropout of low-productivity firms. Finally, innovation itself requires labor, thus intensifying the previous channel. We will show empirically that the net effect of innovation on the number of firms is negative.

Aggregate trade flows. Following Costinot and Rodríguez-Clare (2014), $X_{ij}(\phi)$ defines the total value of country j's imports from country i (Eaton and Kortum, 2002), such that

$$X_{ij}(\phi) = Y_j P_j^{\sigma-1} N_i \int_{\underline{\phi}_i}^{\infty} \chi_{ij}(\phi) p_{ij}(\phi)^{1-\sigma} f(\phi)d\phi. \tag{18}$$

Here, $Y_j = \sum_i X_{ij}$ denotes country j's total expenditures. The expenditure share λ_{ij} of spending on goods imported to country j from country i relative to overall spending from market j defines the usual gravity equation (see Anderson, 1979; Costinot and Rodríguez-Clare, 2014). Formally,

$$\lambda_{ij} = \frac{X_{ij}}{Y_j} = \frac{Y_j P_j^{\sigma-1} N_i \int_{\underline{\phi}_i}^{\infty} \chi_{ij}(\phi) p_{ij}(\phi)^{1-\sigma} f(\phi)d\phi}{P_j^{1-\sigma}}, \tag{19}$$

where $Y_j = \sum_k X_{kj}$ denotes country j's aggregate expenditures. The aggregate price index P_j, which is defined by

$$P_j = \left(\sum_k N_k \int_{\Phi} \chi_{kj}(\phi) p_{kj}(\phi)^{1-\sigma} f(\phi)d\phi \right)^{\frac{1}{1-\sigma}}, \tag{20}$$

inversely relates to the number of firms (N_k) and the export probability (χ_{kj}), and is a positive function of the price level (p_{kj}). Notice that the price index also depends on the optimal investment level. Importantly, using more advanced technologies drives down the aggregate price index by increasing the number of firms ($\sum_k N_k$) and the export probability (χ_{kj}), while simultaneously the price levels are lower (p_{kj}). As a consequence, technology improvements lead to a decline in the aggregate price index.

Goods market. In equilibrium, country i's labor income must be equal to the expenditures spent by consumers in all countries on goods produced in country i. Formally,

$$w_i L_i = \sum_{j \in J} \lambda_{ij} w_j L_j, \tag{21}$$

where λ_{ij} denotes the trade share as specified before.

4.3.4 Equilibrium

A vector of five endogenous variables $\{\kappa_i, w_i, N_i, P_i, \lambda_{ij}\}_{i=1}^{J}$ defines the equilibrium that solves the following five equations: the aggregate price index (20), the number of firms (17), the gravity equation (18), the goods market clearing (21) and the optimality condition for R&D investment (13). The set of equilibrium conditions then automatically satisfy the free entry condition.

4.3.5 Welfare

The welfare level in country j is given by the respective ratio between the wage rate and the corresponding CES price index, i.e., w_j/P_j. In the main simulation exercise, we analyze exogenous scenarios of trade liberalization by lowering iceberg trade costs from τ_{ij} to τ'_{ij}, where we assume $\tau'_{ij} < \tau_{ij}$ and $\tau'_{ii} = \tau_{ii}$. This leads to the following expression for the percentage changes of welfare (Nigai, 2017):

$$\Delta Wel = 100\% \times \left[\ln\left(\frac{w'_j}{w_j}\right) - \ln\left(\frac{P'_j}{P_j}\right)\right] \tag{22}$$

Given the definition of the CES price index, $P_j = \sum_k N_k \int_\Phi \chi_{kj}(\phi) p_k(\phi)^{1-\sigma} f(\phi) d\phi$, we can rewrite the change in welfare as:

$$\Delta Wel = 100\% \times \left[\ln\left(\frac{w'_j}{w_j}\right) - \ln\left(\frac{\left(\sum_{k\in J} N'_k \int_{\underline{\phi}_k} p'_{ik}(\omega)^{1-\sigma} \chi'_{kj}(\omega) d\omega\right)^{\frac{1}{1-\sigma}}}{\left(\sum_{k\in J} N_k \int_{\underline{\phi}_k} p_{ik}(\omega)^{1-\sigma} \chi_{kj}(\omega) d\omega\right)^{\frac{1}{1-\sigma}}}\right)\right] \tag{23}$$

Several properties stand out. First, given the symmetry of markets and conditional on the choice of wage rate w_i as the numéraire, changes in the aggregate price index P_j drive the welfare gains. Hence, welfare is increasing in the number of varieties (N_k). Second, welfare inversely relates to the price level $p_{ik}(\phi)$ since higher prices negatively affect the number of goods affordable to the consumer. Further, welfare positively correlates to the export probability given that more firms serve the export market. A novel feature is that adopting technology encourages firms to charge lower price levels and serve the foreign destination market with a higher probability. While the overall number of firms is increasing, the number of domestic firms (N_j, from country j's point of view) is decreasing as a result of the stronger competition for labor.

4.4 Model calibration

We use a stylized calibration to quantify the effects of interdependent market entry and innovation on aggregate welfare in the presence of trade liberalization. For the baseline specification, we assume $J = 4$ countries, where every firm can potentially serve all destination markets, including the home market.

First, we restrict the returns on investment parameter to the set $\gamma \in \{0, 0.20, 0.22, ..., 0.30\}$. Overall, larger values of the parameter reflect larger returns on a given investment choice while for $\gamma = 0$, firms have no incentives to hire workers. We restrict the returns to $\gamma \leq 0.30$, mostly to avoid that larger investment returns negatively affect firm-behavior due to the decreasing returns to scale assumption. To be precise, the parameter γ does not capture the strength of interdependence. Strictly speaking, the number of markets jointly influencing the investment level, defines the degree of interdependence, while the parameter γ only scales the innovation choice. We follow Broda and Weinstein (2004) by choosing an elasticity of substitution between goods of $\sigma = 4$.[8]

[8]Note that the optimal pricing depends on the scaling $\gamma/(\sigma - 1)$.

Furthermore, we need to make choices for the market entry costs, which affect the firm's export probability, its expected profits, and finally, the optimal technology level. Arkolakis (2010) presents a thorough discussion of the uniform fixed costs, arguing that only sufficiently high uniform fixed costs explain a reasonable firm entry pattern resulting from the free market entry assumption. We set foreign market entry costs to $f_{ij} = 1e^5$ and choose domestic market entry costs of $f_{ii} = 1e^4$, where the choice is such that the foreign market entry costs are substantially larger than for the domestic market given that foreign market entry requires more complex and costly legal involvements which occur when setting up the production structure. Further, our choice ensures a reasonable distribution for the market entry probability in the presence of the stochastic fixed costs.

We follow Nigai (2017) and normalize the participation costs to $f_i^e = 1$ unit of labor, which is — in comparison to the market fixed costs — sufficiently low to not change results fundamentally. Intuitively, the free entry condition implies that the profits earned by all firms are sufficient to cover the entry costs of all firms, including those which leave the market after learning their productivity.

Further, we specify the shape and location parameters for the two Pareto functions of productivity $f(\phi)$ and the stochastic component of the fixed costs, $g(\epsilon)$. In the baseline scenario, we set the parameters (b, β) of the productivity function equal to $(2, 2)$ while assuming for (a, α) the set $(1, 1)$.[9] The choice ensures that sufficient probability mass concentrates around smaller values, which is important when studying the investment choice for low-productivity firms. Further, a large stochastic fixed costs component lowers the effective fixed costs due to the inverse relationship, so that our choice ensures sufficiently large effective market entry costs to ensure the self-selection of high-productivity firms in serving foreign markets.

Table 4.2: Overview of Parameters

	Parameter	Value
γ	Returns on investment	$\{0, 0.20, 0.22, ..., 0.30\}$
σ	Substitution elasticity	4
f_{ij}, f_{ii}	Market entry costs	$1e^5$, $1e^4$
f_i^e	Participation costs	1
a	Location parameter fixed costs	1
b	Location parameter productivity	2
α	Shape parameter fixed costs	1
β	Shape parameter productivity	2
η_i	Efficiency of R&D Investment	1
L	Aggregate labor force	400

Notes: This table displays the parameters for the baseline specification.

To simplify matters, we assume a homogeneous efficiency level $\eta_i = 1$ for all markets, similar to the linear cost structure, which implies level-independent marginal innovation costs. Finally, we assume symmetry in the market size, $L_i = 100$, summing to an aggregate of $L = 400$. An overview of all parameters and variable choices is in Table 4.2.

[9] The grid of productivity values ϕ is based on the quantile function of the Pareto function $G^{-1}(p) = 1/(1-p)^{1/\beta}$, where β denotes the shape parameter and the value for the quantile $0 < p < 1$. We set $p = 0.001$ and $(1 - p) = 0.999$.

4.5 The effect of market interdependence

In this section, we evaluate the effect of innovation on aggregate welfare and underlying firm-specific outcome variables. First, we emphasize how different investment returns affect firms in their (i) technology adoption, (ii) pricing-to-market choices, (iii) market-specific export probabilities, (iv) composite (effective) productivity levels, (v) expected aggregate profits and (vi) weighted sales shares. We also discuss the influence of additional technologies on the number of varieties and the inequality — measured by the Gini-index of expected aggregate profits. In a second exercise, we emphasize the impact of a different number of (potential) export markets (J) on firm-specific choices. Finally, we combine the previous insights to argue why market integration leads to both higher welfare levels and respective welfare gains, although the latter scenario allows for more degrees of freedom in choosing investment levels.

4.5.1 Effects of the returns on investment

In this exercise, we vary the scaling parameter of the optimal technology choice, γ. The main finding is that higher returns drive the investment choice, enabling high-productivity firms to choose higher innovation levels. In particular, given the relationship between the firm's optimal investment level and its initial productivity level, we observe a selection effect, i.e., highly productive firms have higher optimal investment levels, which magnifies the spread in effective productivity by shifting resources to these firms at the expense of low-productivity firms. Throughout the analysis, we hold bilateral trade costs constant and assume symmetric markets in terms of the market size (L_i).

Impact on optimal investment levels. We first discuss the relationship between the optimal investment and its returns for different productivity levels. Panel (a) of Figure 4.2 displays the findings. For all parameter values (γ), high-productivity firms have a higher optimal investment level in equilibrium than low-productivity firms. The observed pattern follows directly from the positive relationship between the initial productivity level and market-specific revenues, as well as expected aggregate profits. High-productivity firms can charge lower prices because the marginal production costs are decreasing in productivity, which leads to larger market shares enabling in particular high-productivity firms to cover the investment costs.

A second finding relates to the size of investment returns. For every firm, a higher value of $\gamma_2 > \gamma_1$ results in more investment activity, constituting a positive relationship between the two variables with one exception. For sufficiently large values of γ, there is the following trade-off. On the one hand, decreasing returns to scale ($\gamma < 1$) lead to lower investment levels, while second, the lower investment is subject to a larger scaling ($\gamma_2 > \gamma_1$). As we will see later, the lower technology level leads to a small decline in welfare. Our simulation exercise also shows that for any two values γ_1, γ_2, the difference in the optimal investment level is an increasing function of the ex-ante productivity (ϕ).

Impact on optimal pricing. It follows from equation (6) that pricing-to-market leads to a constant markup over marginal costs, with the marginal costs depending on country i's wage level (w_i) and the bilateral iceberg trade costs with market j (τ_{ij}). An inverse influencing factor is the technology level scaled by the returns γ. Formally, this relationship nests the standard pricing rule by Melitz (2003) as a special case for $\gamma = 0$, i.e., when technology adoption has no returns, and no firm invests.

Panel (b) of Figure 4.2 shows that the price level is decreasing in the returns, which follows from the inverse relationship with technology. Intuitively, firms lower their marginal costs and, given the constant markup, set a lower price level. For sufficiently large returns, the effect will be weaker because of the decreasing returns and the lower optimal technology choice.

Further, our results show that more productive firms charge lower prices, an effect which consists of two parts. For one, a higher initial productivity level directly lowers marginal costs and the resulting optimal price. A related indirect effect links the firm's ex-ante productivity level to the chosen technology level, which also affects the optimal price level.

Impact on exporting probabilities. Given the probabilistic notion of exporting, Panel (c) of Figure 4.2 shows the relationship between the investment returns and the export probability.

For almost all investment returns, the export probability is increasing in the firm's ex-ante productivity level (ϕ) while for sufficiently high productivity levels, firms export with certainty. Our results also indicate that higher values $\gamma_2 > \gamma_1$ positively affect a firm's export probability.

Impact on effective productivity levels. Although the firm's ex-ante productivity level is constant, the corresponding effective productivity is increasing in innovation. To formalize the idea, we define the effective productivity ξ_i as a composite of the initial productivity ϕ and the additional investment choice, leading to (see Appendix 4.A for details):[10]

$$\xi_i(\phi) = \phi \left(1 + \kappa_i(\phi)\right)^{\gamma/(\sigma-1)} \tag{24}$$

Intuitively, a higher productivity correlates with lower price levels both as a result of its direct influence, but also by raising the optimal technology level. Panel (d) of Figure 4.2 shows that the effective productivity is increasing in its ex-ante level (ϕ), and shows that for a given productivity level, larger returns correlate to larger composite productivities.

Impact on weighted sales shares and expected profits. It is appropriate to evaluate the weighted sales shares ('relative firm size') when determining the degree to which resources are shifted to high-productivity firms. The weighted sales are given by the revenues, weighted by income levels (Y_j), exporting probabilities (χ_{ij}), and the share of firms with productivity ϕ. Formally, the sales are given by

$$PQ_{ij,\text{weighted}}(\phi) = \frac{1}{N_i}\left[\frac{p_{ij}(\phi)^{1-\sigma}}{P_j^{1-\sigma}} Y_j \chi_{ij}(\phi) f(\phi) d\phi\right]. \tag{25}$$

The corresponding shares are given by:

$$\rho_{ij,\text{weighted}}(\phi) = \frac{PQ_{ij,\text{weighted}}(\phi)}{\sum_\phi PQ_{ij,\text{weighted}}(\phi)} = \frac{p_{ij}(\phi)^{1-\sigma}\chi_{ij}(\phi) Y_j f(\phi) d\phi}{N_i P_j^{1-\sigma}\sum_\phi PQ_{ij,\text{weighted}}(\phi)}. \tag{26}$$

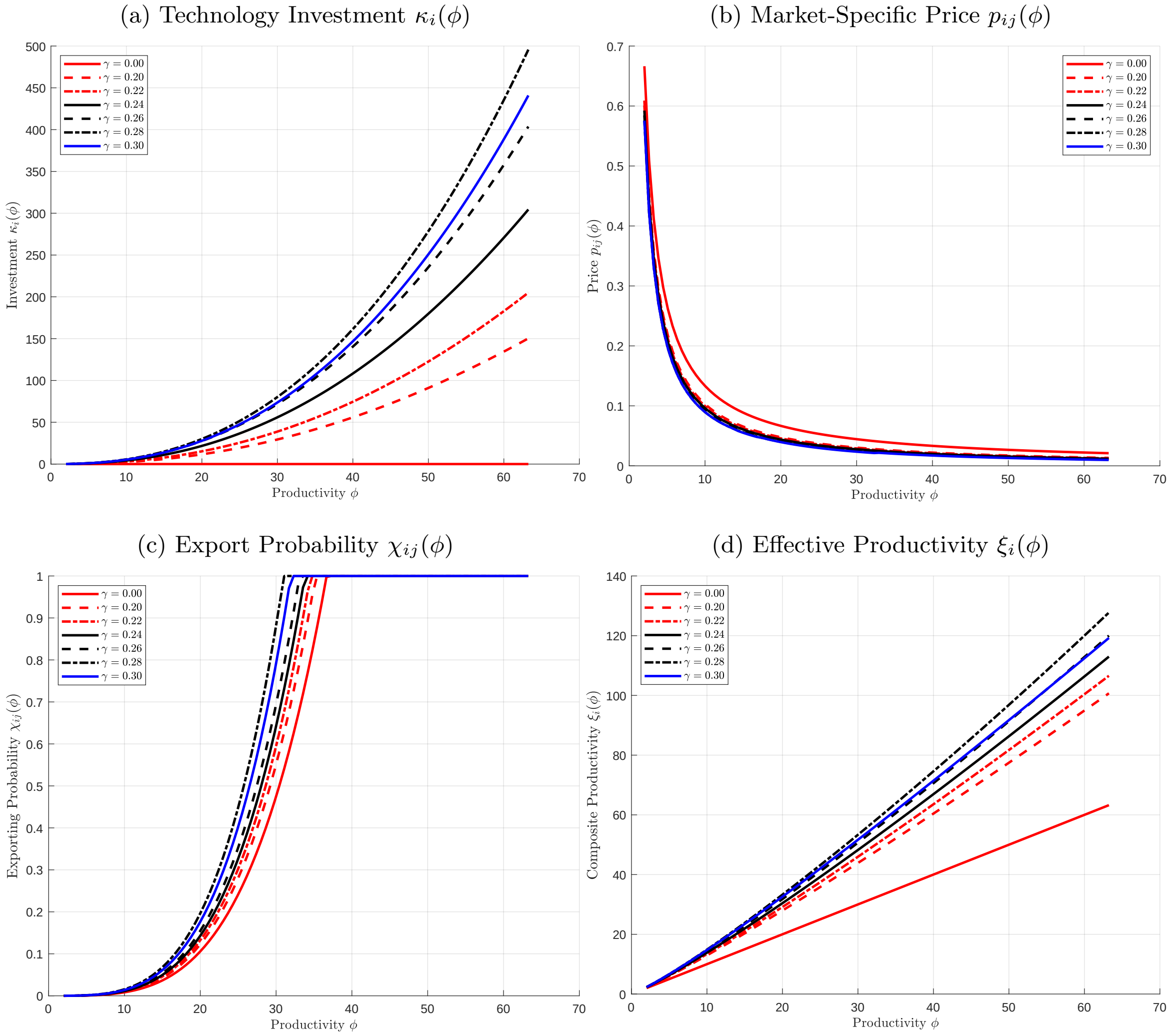
Notice that the weights $(1/N_i)f(\phi)d\phi$ include information about the number of firms and the respective density distribution of the productivity.[11] To observe the shifting of resources to highly productive firms, the following condition must be satisfied. For low returns, low-productivity firms have (relatively) larger shares than in the presence of high returns, and respectively, high-productivity firms have (relatively) larger shares when the returns are high. Panel (a) of Figure 4.3 displays the confirming results. In particular, low-productivity firms are relatively better off when the returns are low, and all firms have lower innovation levels.

Intuitively, highly productive firms attract more demand $q_{ij}(\phi)$ given their lower price level. When the returns on innovation are substantial, high-productivity firms increase their productivity advantage at the expense of low-productivity firms. In line with Melitz (2003), the losses from the low-productivity firms must be offset by the respective gains from highly productive firms to satisfy the free entry condition. Besides, we evaluate the expected aggregate profits as

[10] Evaluating the average productivity of all firms in the market would include the likelihood of serving a specific market j. Given that more productive firms are also more likely to export, this does not affect overall patterns.

[11] The change in the density function $d\phi$ is required to discretize the value space of productivity. If the function was perfectly continuous, the weighting would be only by the density function $f(\phi)$.

Figure 4.2: Influencing Factor: Investment Returns γ



Notes: This figure shows firm-specific results for different returns on investment (γ). Panel (a) shows the technology investment, Panel (b) shows the pricing-to-market, Panel (c) displays the export probability, and Panel (d) shows the composite productivity.

determined by equation (12). The results are in Panel (b) of Figure 4.3. The expected aggregate profits are increasing in the returns and along with the productivity distribution.

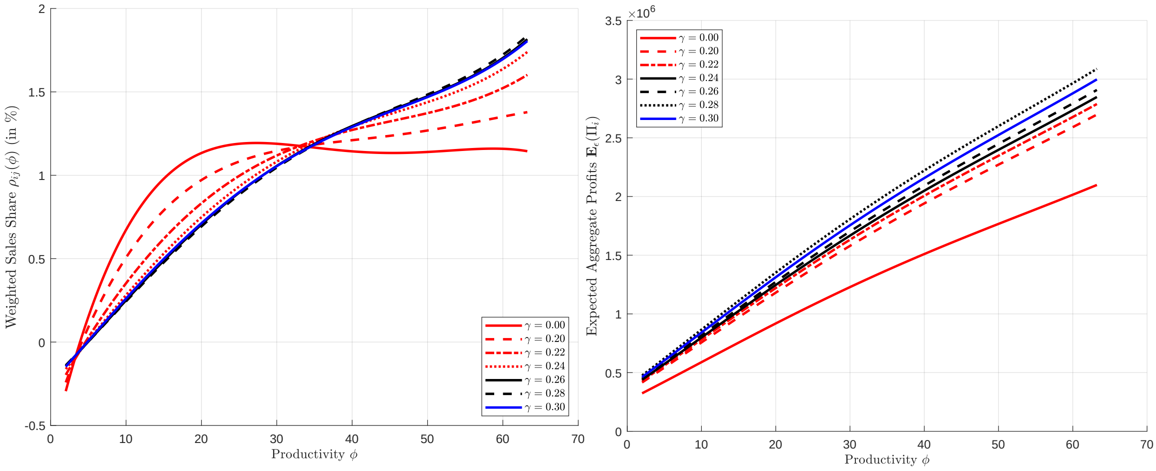
Impact on inequality. If all firms had an identical level of aggregate expected aggregate profits, the distribution would be perfectly symmetric. However, our findings so far show that high-productivity firms gain additional market shares at the expense of low-productivity firms, which implies that the inequality across the productivity distribution is increasing. Accordingly, a range of highly productive firms are sufficiently productive to serve the export market, while low-productivity firms are forced to leave the market. To draw a clearer picture, we calculate the Gini-index for a variety of D_i different firms,

$$G_i = \frac{2}{D_i} \sum_{\phi} v_\phi - \frac{D_i + 1}{D_i} \quad \text{where } v_\phi = \frac{\sum_{k=1}^{\phi} x(k)}{\sum_{k=1}^{D} x(k)}. \tag{27}$$

We measure the Gini-coefficient in terms of expected overall profits, setting $x(k, \phi) = \mathbb{E}_\epsilon(\Pi_i(\phi))$. Panel (a) of Table 4.3 shows the results. The main finding is that the distribution of the expected

Figure 4.3: Influencing Factor: Investment Returns γ (cont.)

(a) Weighted Sales Share $\rho_{ij}(\phi)$ (b) Expected Aggregate Profits $\mathbb{E}_\epsilon(\Pi_i(\phi,\gamma))$



Notes: This figure shows firm-specific results for different returns on investment (γ). Panel (a) shows the weighted sale share and Panel (b) shows the expected aggregate profits.

profit becomes (more) unequal with larger returns. Accordingly, the Gini-index varies between 0.609 ($\gamma = 0$) and 0.651 ($\gamma = 0.30$). Intuitively, more productive firms have higher sales shares, which improves their relative position in the expected aggregate profits distribution relative to less productive firms.[12] Yet, the decreasing returns to scale may contribute to lower inequality in the presence of lower investments.

Table 4.3: Measure of Inequality: The Gini-index G_i

	(a) Gini-index						
	$\gamma = 0.00$	$\gamma = 0.20$	$\gamma = 0.22$	$\gamma = 0.24$	$\gamma = 0.26$	$\gamma = 0.28$	$\gamma = 0.30$
Baseline	0.609	0.652	0.653	0.653	0.653	0.652	0.651
	(b) Gini-index — Markets J						
$J = 3$	0.606	0.649	0.650	0.650	0.650	0.649	0.648
$J = 4$	0.609	0.652	0.653	0.653	0.653	0.652	0.651
$J = 6$	0.612	0.656	0.657	0.657	0.657	0.656	0.655
$J = 8$	0.614	0.659	0.660	0.660	0.660	0.660	0.658
$J = 10$	0.616	0.664	0.665	0.665	0.665	0.664	0.663

Notes: This table displays the Gini-index for different returns on investment (γ). Panel (a) shows the results for the baseline scenario, Panel (b) considers different numbers of markets (J).

Impact on the number of firms. We finally evaluate how the set of investment returns influences the domestic number of firms. Intuitively, the number of firms correlates with the market size and the demand for labor. Given its fixed supply, the increasing labor demand raises real wages, thus, decreasing the number of domestic firms. To be precise, the least productive firms are forced to leave the market, given the higher real wages. Panel (a) of Table 4.4 confirms

[12] A broad literature finds that the interaction between export probabilities, heterogeneity in technological, and international trade costs leads to increasing inequality (see, e.g., Yeaple, 2005; Egger and Kreickemeier, 2012).

Table 4.4: Number of Firms N_i (Hundreds) — Integrated Markets

	(a) Number of firms						
	$\gamma = 0.00$	$\gamma = 0.20$	$\gamma = 0.22$	$\gamma = 0.24$	$\gamma = 0.26$	$\gamma = 0.28$	$\gamma = 0.30$
Baseline	6.17	5.11	5.02	4.95	4.91	4.90	4.91
	(b) Number of firms — Markets J						
$J = 3$	10.34	7.45	7.29	7.17	7.11	7.10	7.14
$J = 4$	6.17	5.11	5.02	4.95	4.91	4.90	4.91
$J = 6$	2.94	2.89	2.85	2.82	2.80	2.78	2.77
$J = 8$	1.72	1.87	1.86	1.84	1.83	1.82	1.81
$J = 10$	1.14	1.47	1.47	1.46	1.45	1.44	1.42

Notes: This table shows the number of firms for integrated markets and different investment returns (γ). Panel (a) shows the results for the baseline scenario, Panel (b) considers different numbers of markets (J). The numbers are in hundreds.

our intuition with the respective number of firms between 6.17 ($\gamma = 0$) and 4.91 ($\gamma = 0.30$, all in hundreds). The respective increase in the number of varieties for $\gamma = 0.30$ follows from the lower investment level resulting from the decreasing returns to scale of innovation.

4.5.2 Effects of the number of markets

In this exercise, we evaluate how a different number of markets (J) affects firms in their respective optimization. The idea for this analysis is by Schmookler (1954) and Lileeva and Trefler (2010), who argue that the number of destination markets influences the exporting behavior of firms. Both papers postulate that improved access to foreign markets raises the effective market size and creates additional incentives to serve foreign markets. Similarly, Eaton et al. (2004) argue that market-specific fixed costs account for the positive relationship between the number of exporters and the market size.[13]

Throughout the analysis, we consider J symmetric markets, where $J = \{3, 4, 6, 8, 10\}$. Symmetry implies that markets equally share the constant aggregate labor force, which leads to a decreasing market size in the number of markets. Further, we assume high returns on investment ($\gamma = 0.30$) and set the aggregate labor force to $L = 400$.[14]

A change in the number of markets has two opposing effects. For one, the decreasing labor force per market strengthens the competition for labor, lowers the number of varieties, and requires firms to pay higher aggregate fixed costs. However, a larger number of markets positively affect potential profits because high-productivity firms gain market-shares at the expense of leaving low-productivity firms. To determine which effect dominates, we evaluate the firm-specific investments, market entry probabilities, weighted sales shares, and expected aggregate profits. The results are in Figure 4.4.

Panel (a) shows a negative relationship across the entire productivity distribution, given the more expensive market entry. The intuition is as follows. Although improved technology is used in more markets, the optimal investment also depends on the market entry probabilities (χ_{ij}), the income levels (Y_j), and the market entry costs (f_{ij}). It follows that a smaller labor force (L_i) shrinks the available income and leads to stronger competition for labor. Moreover, according to equation (13), the fixed costs show up both in the numerator and in the denominator (scaled by the parameter $\alpha + 1$, see the formula for V_{ij}^*) of the market entry equation. Given the restriction

[13] Using French firm-level data, Eaton et al. (2004) provide evidence on the predictive power of the market size on the export decision.

[14] The results are robust to both lower and higher returns γ.

that $\alpha + 1 > 1$, the expression in the denominator dominates and the overall effect on market entry costs is negative.

Panel (b) confirms the idea that lower income levels and lower technology upgrading reduce the market entry probability for market j. This pattern is driven by the mutual influence of investments and market entry probabilities on each other. Intuitively, a larger aggregate market size would lead to higher sales if the aggregate labor force increased as well. However, given the constant aggregate labor force L, there are fewer resources per destination market, and given the symmetry of foreign markets, firms still serve all markets with an identical, yet smaller probability.

To extend our argument, we also present sales shares and expected aggregate profits in Panel (c) and Panel (d) of Figure 4.4. Importantly, the expected profits are increasing in the number of markets, while for the weighted sales shares, the pattern is different. In particular, high-productivity firms benefit from an increasing number of markets, given that they export with certainty, contrary to low-productivity firms with lower market-specific sales shares.

We proceed to evaluate the impact of the aggregate market size on the Gini-index and the domestic number of firms. Starting with the Gini-index, Panel (b) of Table 4.3 shows that the Gini-index is an increasing function of J. For $\gamma = 0.30$, the Gini-index is in the range between 0.648 ($J = 3$) and 0.663 ($J = 10$) given the lower labor force per market. We also observe that the positive relationship between the investment returns and the Gini-index is stable across all possible numbers of markets.

The results for the domestic number of firms are in Panel (b) of Table 4.4 and show a steady decline across the number of markets. An increase from $J = 3$ to $J = 10$ leads to a decrease in the respective number of firms from 7.14 to 1.42 (all in hundreds). The observed decline follows directly from the co-movement between the labor force and the number of firms resulting from the stronger competition for labor. The main insight from this exercise is that interdependent market entry influences firm-specific choices. In the next step, we aggregate the firm-specific effects in terms of welfare and evaluate the welfare gains in the presence of trade liberalization.

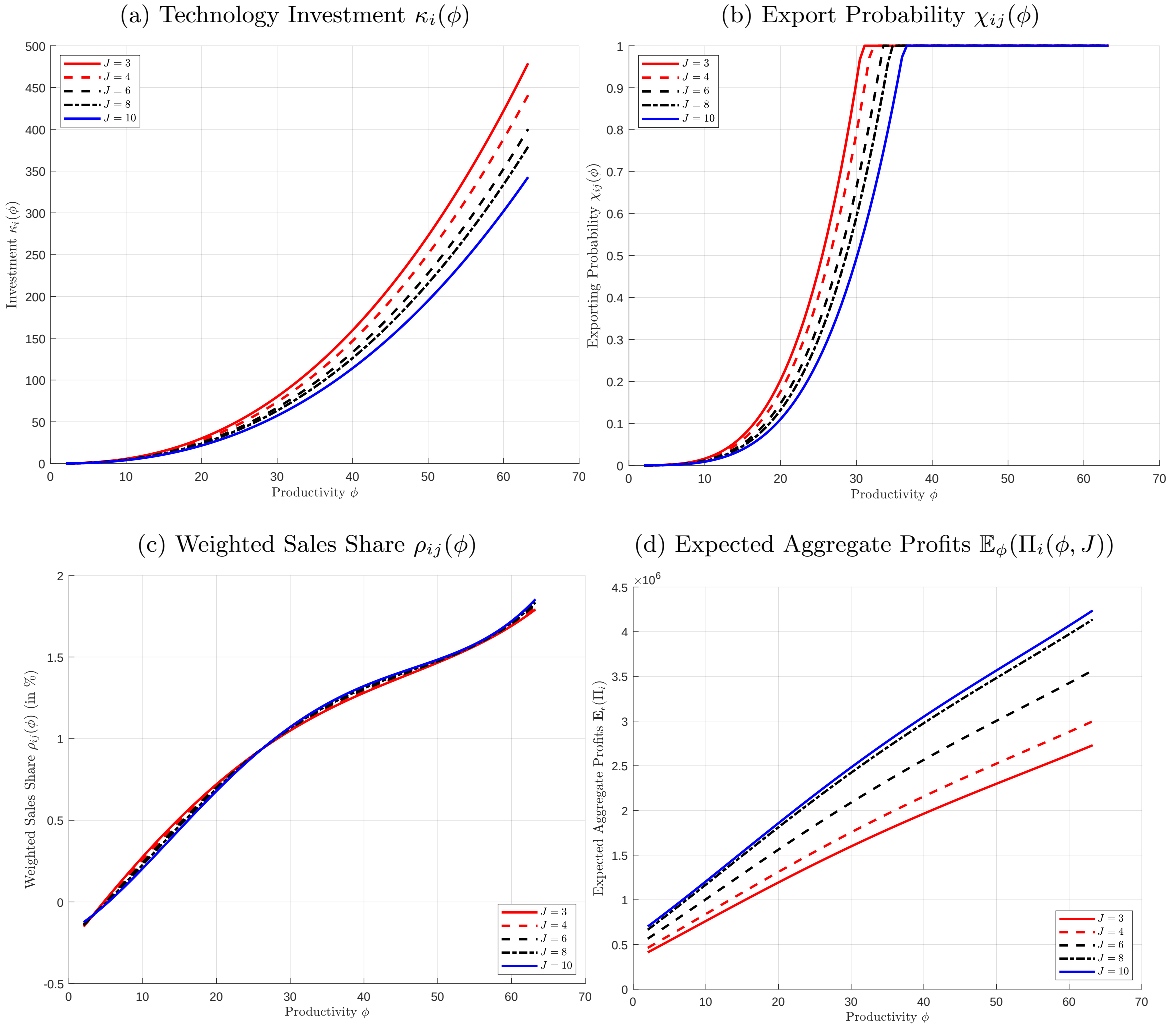
4.5.3 Welfare effects of trade liberalization and innovation

In this section, we evaluate the impact of trade liberalization on firm-specific variables and aggregate welfare. Given the sensitivity of firm-behavior when changing the returns or the number of destination markets, the question is how this affects the welfare levels. This question is even more interesting in the context of trade liberalization and welfare changes. To emphasize the importance of integrated markets, we compare the welfare gains to those for segmented markets, i.e., when firms freely choose market-specific technology levels (κ_{ij}). Ex-ante, it is unclear how the gains differ between the two settings. On the one hand, market-specific technology investments give more degrees of freedom to the optimizing firm. On the other hand, the innovation level per destination market is lower for segmented markets because firms optimize market-specific profits.

Our setup can be summarized as follows. There are no frictions for domestic trade while we assume symmetric trade costs of 20% between the domestic market and all foreign markets. Starting from this equilibrium, we consider a baseline trade cost decline of $|\Delta\tau_{ij}| = 10\%$ between the domestic market and all foreign markets. We repeat this exercise for respective changes of 5% and 15%.

The firm-specific findings on investment, market entry probabilities, and expected profits are in Figure 4.5. Panel (a) shows that lower trade costs positively affect the optimal investment level, while Panel (b) depicts that lower bilateral trade costs make market entry more profitable, and thus, increase the respective market entry probability. Panel (c) confirms that the expected aggregate profits are positively affected by lower trade frictions. Given these insights, we evaluate welfare defined according to equation (22). For a given value of γ, the welfare gains are given

Figure 4.4: Influencing Factor: Number of Markets J



Notes: This figure shows firm-specific results for different numbers of markets (J). Panel (a) displays the technology investment, Panel (b) shows the export probability, Panel (c) displays the weighted sales share, and Panel (d) shows the expected aggregate profits. All results are for $J = 4$, $L = 400$, $\gamma = 0.30$.

by

$$\Delta Wel^{\gamma} = \frac{Wel'_{\gamma}}{Wel_{\gamma}}, \tag{28}$$

where Wel'_{γ} is the welfare level for liberalized trade with τ'_{ij}. Table 4.5 displays the corresponding welfare changes for the set $|\Delta\tau_{ij}| = \{5\%, 10\%, 15\%\}$.[15] In the baseline scenario, the welfare gains vary between 1.86% ($\gamma = 0$) and 1.55% ($\gamma = 0.30$). When the trade cost decline is 15%, the gains vary between 3.32% and 2.62%, preserving the negative relationship between the returns on investment and the respective welfare gains.

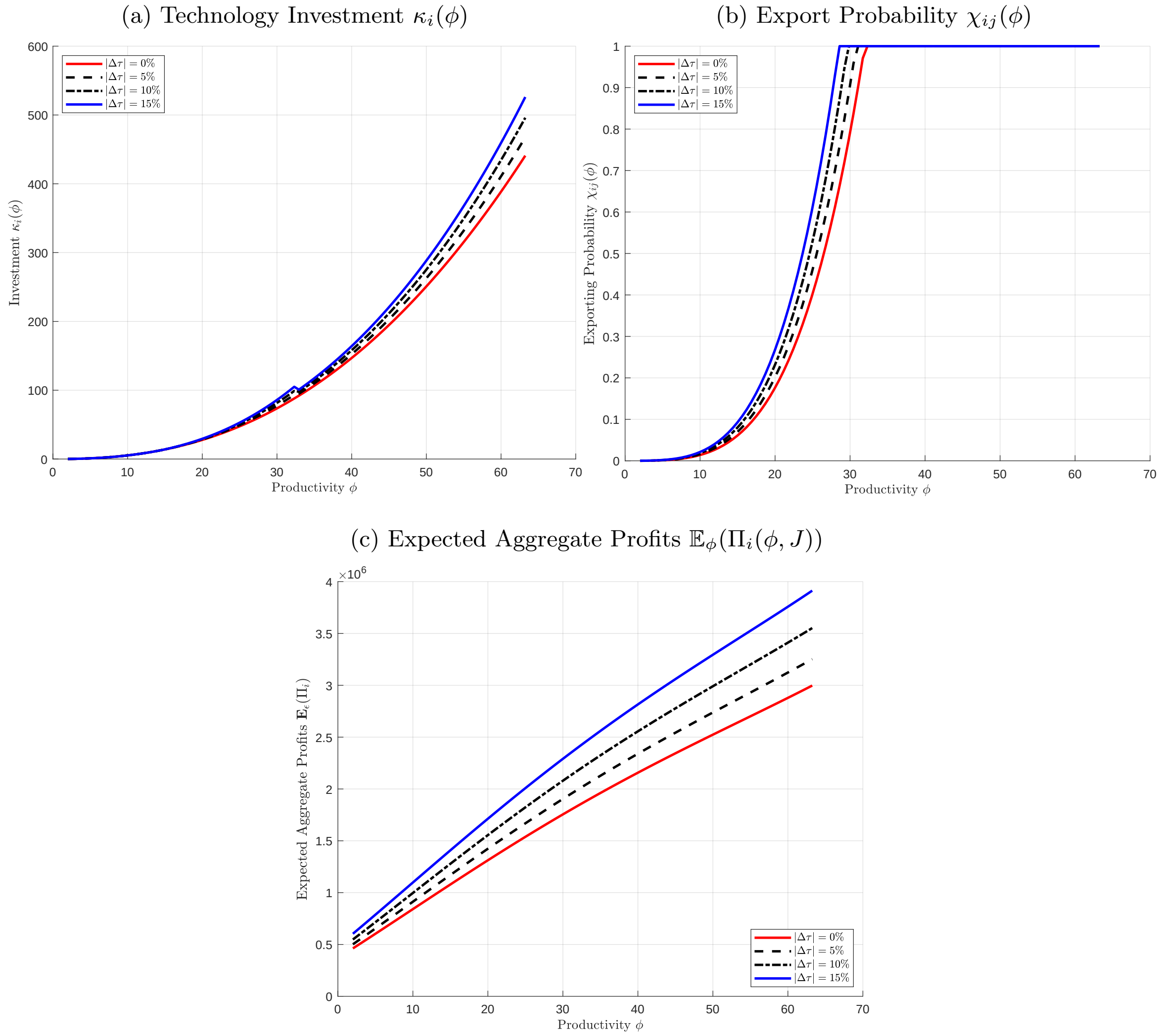
So far, we observe higher gains for higher trade cost reductions, which is quite intuitive and follows the line of argument by Melitz (2003), i.e., lower frictions make foreign market entry and technology adoption more profitable. The resulting increase in the labor demand, and the related real wage rise force less productive firms to exit. In total, only the high-productivity firms export, consumers can buy a larger number of varieties as a result of the improved market

[15] For the sake of simplicity, we use the absolute values of trade cost declines $|\Delta\tau_{ij}| > 0$.

access by foreign firms, all at lower price levels.

A second finding is that the welfare gains are higher for lower investment returns, which may also relate to the decreasing returns to scale assumption and its impact on high returns. On the other hand, it could also be a pure level effect, i.e., higher returns lead to higher welfare levels, given the trade frictions. If the corresponding gains are disproportionate to the gains under trade liberalization, the percentage changes would be lower. To validate this argument, we analyze the welfare gains in detail, looking at different returns and numbers of markets but also comparing the results of integration to those under segmentation.

Figure 4.5: Influencing Factor: Trade Liberalization $|\Delta\tau|$



Notes: This figure shows firm-specific results for different scenarios of trade liberalization ($|\Delta\tau_{ij}|$). Panel (a) displays the technology investment, Panel (b) shows the export probability and Panel (c) displays the expected aggregate profits. All results are for $J = 4$, $L = 400$, $\gamma = 0.30$.

The importance of integrated markets versus segmented markets. We evaluate the importance of market integration by comparing the welfare gains in the presence of trade liberalization to the results under market segmentation. Market segmentation implies a setting in which each firm makes market-specific investments κ_{ij} instead of choosing one level based on the expected aggregate profits.

In the following, we briefly describe market segmentation, which serves as the reference case.

Table 4.5: Welfare Changes of Trade Liberalization $|\Delta\tau_{ij}|$

	$\gamma = 0.00$	$\gamma = 0.20$	$\gamma = 0.22$	$\gamma = 0.24$	$\gamma = 0.26$	$\gamma = 0.28$	$\gamma = 0.30$
$\lvert\Delta\tau_{ij}\rvert = 5\%$	0.77%	0.70%	0.69%	0.68%	0.68%	0.68%	0.67%
$\lvert\Delta\tau_{ij}\rvert = 10\%$	1.86%	1.59%	1.56%	1.54%	1.53%	1.55%	1.55%
$\lvert\Delta\tau_{ij}\rvert = 15\%$	3.32%	2.67%	2.63%	2.60%	2.59%	2.58%	2.62%

Notes: This table displays the welfare changes (in percent) from trade liberalization for different returns on investment (γ).

The market-specific technology choice leads to the optimization of a different objective function. Instead of optimizing the expected aggregate profits, firms optimize the expected market-specific profits. Conditional on exporting, the corresponding profit function is then given by:

$$\mathbb{E}_{\epsilon}[\Pi_{ij}] = \chi_{ij}(\phi)\pi_{ij}(\phi) - \eta_i\kappa_{ij}(\phi)w_i. \tag{29}$$

Optimizing this function leads to the following first-order condition for κ_{ij} (see Appendix 4.A for details)

$$(1+\kappa_{ij}^{*}) = \left[\frac{\gamma a^{\alpha}\left[\frac{1}{\sigma}\left(\frac{\sigma}{\sigma-1}\frac{w_i\tau_{ij}}{\phi}\right)^{1-\sigma}\frac{Y_jP_j^{\sigma-1}}{w_if_{ij}}\right]^{\alpha+1}w_if_{ij}}{\eta_iw_i}\right]^{1/(1-\gamma\alpha-\gamma)}, \quad 1-\gamma\alpha-\gamma>0. \tag{30}$$

It is immediate that the optimal investment level positively correlates to the income level (Y_j), and the aggregate price level (P_j). On the other hand, there is an inverse relationship to the wage level (w_i), the market entry costs (f_{ij}), and the inefficiency parameter (η_i). Further, the relationship to the returns is flexible, given that γ appears both in the exponent and in the numerator. The respective influence is mostly positive, but it can also lead to a decrease in the investment because of the decreasing returns. Notice that these conclusions hold only for the parameter restriction $1-\gamma\alpha-\gamma>0$. Given the respective parameter choice of $\alpha = 1$, we obtain the restriction of $\gamma < 0.5$.[16]

The following argument summarizes the difference between segmented and integrated markets. Since the objective functions differ across the settings, they have different optimal investment levels, which are driven by asymmetries between the markets. Given our assumption of symmetry in the market size and symmetric bilateral trade costs with foreign markets, the only source of heterogeneity between the domestic market and (all) destination markets is the different levels of trade costs, i.e., $\tau_{ii} < \tau_{ij}$. From an ex-ante point of view, we expect the investment level for integrated markets to be larger than for segmented markets, i.e., $\kappa_i(\phi) > \kappa_{ij}(\phi)$ because of the different objective function. We further expect that the domestic investment level is larger than the individual foreign level, i.e., $\kappa_{ii}(\phi) > \kappa_{ij}(\phi)$.

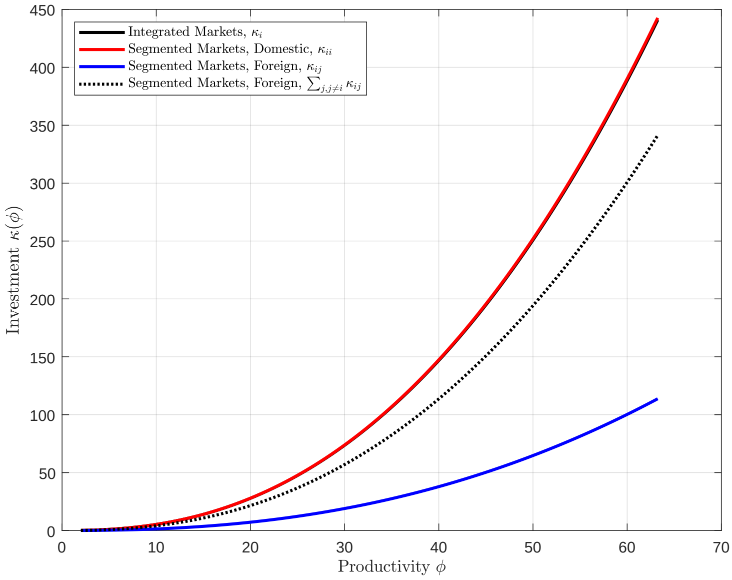
To empirically validate the respective differences, we consider the baseline labor force ($L = 400$), as well the complete set of markets $J = \{3, 4, 6, 8, 10\}$.

We first evaluate the optimal investments for the two settings before liberalizing trade. The results are in Figure 4.6, distinguishing between the technology level for integrated markets (κ_i) and the set of values for segmented markets. This set includes the domestic technology choice (κ_{ii}), the foreign investment choice (κ_{ij}), and the sum across all foreign destinations ($\sum_{j,j\neq i}\kappa_{ij}$). There are two insights.

First, the optimal investment under market integration is higher than for each foreign market

[16]Similar to integrated markets, the decreasing returns to scale lead to no perfectly monotone relationship.

Figure 4.6: Investment Level κ (Before Liberalization)



Notes: This figure shows the optimal investment level for integrated markets ($\kappa_i(\phi)$, solid black line) and segmented markets, in particular, the domestic investment ($\kappa_{ii}(\phi)$, red line), the market-specific foreign investment ($\kappa_{ij}(\phi)$, blue line) and the sum of all foreign investments ($\sum_{j,j\neq i}\kappa_{ij}(\phi)$, dotted black line). All results are for $\gamma = 0.30$, $J = 4$ and before trade liberalization.

individually but lower in comparison to the sum across all foreign destinations ($\sum_{j,j\neq i}\kappa_{ij}$).[17]

Second, the integrated investment level is lower than the respective investment for the domestic market (κ_{ii}). However, this pattern changes after trade liberalization, where we obtain $\kappa_i(\phi) > \kappa_{ii}(\phi)$.[18] Further, the results confirm that the domestic investment (κ_{ii}) is larger than the market-specific investment for foreign markets (κ_{ij}). Formally, given the initial trade frictions, we can summarize our findings as follows:

$$\sum_j \kappa_{ij}(\phi) > \kappa_{ii}(\phi) > \kappa_i(\phi) > \kappa_{ij}(\phi) \tag{31}$$

Intuitively, choosing one optimal investment level for all destinations leads to the larger availability of additional technology to all markets compared to a setting with market-specific choices. This argument holds even though the sum of all market-specific levels (including the home market) is higher for segmented markets, i.e., $\sum_j \kappa_{ij}(\phi) > \kappa_i(\phi)$. This finding is robust between different returns and more pronounced for a larger number of markets.

We proceed to compare the initial welfare levels and the resulting gains from trade liberalization. The results are in Table 4.6 where Panel (a) and Panel (c) display the initial welfare levels. First, the welfare levels are identical for zero-returns ($\gamma = 0$) because firms invest in neither scenario, and the two settings become indistinguishable. Yet, the welfare level is decreasing in the number of markets, which confirms the intuition that the export probability is lower because firms need to cover higher aggregate market entry costs. In numbers, the initial welfare level varies between 1.503 ($J = 3$) and 0.987 ($J = 10$).

Second, for a given number of markets, higher returns lead to an increasing or u-shape of the welfare levels, displaying positive welfare changes from technology adoption. The decline at the upper bound of γ follows from the decreasing returns to scale. The observed patterns are quite intuitive: up to a certain return value γ, higher returns positively affect the optimal investment level while the optimal price goes down. On the other hand, a larger number of markets requires

[17] This pattern only holds for low values of J or large trade frictions. The relationship $\kappa_i(\phi) > \kappa_{ij}(\phi)$ is robust.

[18] We present a graph of the optimal investment level after trade liberalization in Figure 4.8 in Appendix 4.B.

more substantial payments of market entry costs.

Panel (b) and Panel (d) of Table 4.6 display the corresponding welfare gains from trade liberalization. For $\gamma = 0$, the welfare gains are identical and in a range between 0.76% ($J = 3$) and 5.61% ($J = 10$). Moreover, the welfare gains are increasing in the number of markets but follow a decreasing pattern for higher returns relative to $\gamma = 0$. A comparison between integrated and segmented markets reveals higher gains for integrated markets, up to a factor of almost three for small J (0.83% versus 0.32%). For the observed patterns, there are several explanations.

First, the welfare gains are increasing in the number of markets (J) because the inverse relationship between κ and J is compensated by the positive impact of lower trade costs on innovation and the market entry probability for firms producing for more destinations. The argument is as follows: Initially, the welfare level is negatively affected by a larger number of markets because firms need to pay market entry costs, and on the other hand, there is a lower labor force per market. Given the trade cost decline, both the export probability and the investment level increase, an effect that is multiplied in the presence of more markets.

Second, the decreasing relationship between the welfare gains and the investment returns is particularly prominent between zero-returns and positive returns. The initial decline in welfare gains — when switching from $\gamma = 0$ to $\gamma = 0.20$ — is the result of a level effect since positive investment levels also lead to welfare gains. These gains from an investment are even higher than the corresponding gains from trade liberalization. Consequently, the magnitude of the percentage changes declines. On the other hand, switching the returns from $\gamma = 0.28$ to $\gamma = 0.30$ leads to similar gains, although we observe a decline in the initial welfare level (i.e. before trade liberalization). This comes from the decreasing returns to scale and the resulting decline in firm-specific investments, leading to a smaller percentage change when trade costs go down.

Third, we find higher welfare gains for integrated markets compared to segmented markets, which is due to the persistence in the innovation pattern, i.e., $\kappa_i(\phi) > \kappa_{ij}(\phi)$. On the other hand, for $J = 10$, the decreasing returns seem to affect integrated markets more severely, thus leading to lower gains. Alternatively, the cumulative sum of firm-specific investments outperforms the integrated choice if the number of markets is sufficiently large. However, the welfare levels of integrated markets remain larger than for segmented markets.

Trade liberalization correspondingly affects the number of firms. Table 4.8 (see Appendix 4.B for details) shows the initial numbers for segmented markets. Since market-specific investment leads to disadvantages compared to integration, the respective number of firms is larger (see Table 4.4 for the results of integration). Our findings are robust between different returns on investment and to the set of destination markets. Further, the number of firms is a decreasing function of J. The observed pattern follows from the fact that a larger number of markets drive down the labor force per market, strengthening the competition for labor. Lower trade costs lead to a decline in the number of firms, both for integration and segmentation, as well as for an increasing number of markets. The results are in Table 4.9 (see Appendix 4.B).

Summary. Our quantitative exercise shows the importance of considering interdependent market entry in a multi-country setup. Important influencing factors are investment returns and the number of markets, which both affect welfare by changing firm-specific behavior. Our results differ significantly from the findings by Atkeson and Burstein (2010) who argue that despite its impact on heterogeneous firms' exit, export, and process innovation decisions, trade liberalization does not lead to changes in welfare because responses in product innovation offset the impact of changes in these decisions on welfare. We find different patterns for integrated and segmented markets showing that the returns on investment affect the size of the gains.

Table 4.6: Baseline: Welfare Changes for $L = 400$

	$\gamma = 0.00$	$\gamma = 0.20$	$\gamma = 0.22$	$\gamma = 0.24$	$\gamma = 0.26$	$\gamma = 0.28$	$\gamma = 0.30$
(a) Integrated markets — Wel							
$J = 3$	1.503	2.191	2.210	2.219	2.221	2.225	2.220
$J = 4$	1.355	2.056	2.075	2.085	2.087	2.089	2.087
$J = 6$	1.174	1.868	1.888	1.900	1.901	1.904	1.902
$J = 8$	1.063	1.740	1.760	1.771	1.773	1.766	1.749
$J = 10$	0.987	1.685	1.706	1.718	1.720	1.724	1.723
(b) Integrated markets — $\Delta Wel^{(\|\Delta\tau_{ij}\|=10\%)}$							
$J = 3$	0.76%	0.86%	0.84%	0.83%	0.83%	0.83%	0.83%
$J = 4$	1.86%	1.59%	1.56%	1.54%	1.54%	1.54%	1.55%
$J = 6$	3.49%	2.74%	2.70%	2.68%	2.67%	2.67%	2.69%
$J = 8$	4.60%	3.59%	3.54%	3.51%	3.51%	3.51%	3.53%
$J = 10$	5.61%	4.55%	4.50%	4.48%	4.47%	4.47%	4.49%
(c) Segmented markets — Wel							
$J = 3$	1.503	2.173	2.191	2.201	2.203	2.207	2.200
$J = 4$	1.355	2.018	2.037	2.047	2.048	2.050	2.056
$J = 6$	1.174	1.804	1.822	1.832	1.834	1.826	1.822
$J = 8$	1.063	1.658	1.677	1.686	1.688	1.687	1.662
$J = 10$	0.987	1.583	1.602	1.612	1.614	1.618	1.617
(d) Segmented markets — $\Delta Wel^{(\|\Delta\tau_{ij}\|=10\%)}$							
$J = 3$	0.76%	0.32%	0.31%	0.30%	0.30%	0.31%	0.32%
$J = 4$	1.86%	1.09%	1.06%	1.05%	1.05%	1.06%	1.08%
$J = 6$	3.49%	2.45%	2.42%	2.40%	2.39%	2.41%	2.44%
$J = 8$	4.60%	3.51%	3.47%	3.45%	3.44%	3.46%	3.49%
$J = 10$	5.61%	4.60%	4.56%	4.54%	4.53%	4.55%	4.57%

Notes: Panel (a) shows the initial welfare level for integrated markets. Panel (b) shows the welfare gains from trade liberalization ($|\Delta\tau_{ij}| = 10\%$) for integrated markets. Panel (c) shows the initial welfare level for segmented markets. Panel (d) shows the welfare gains from trade liberalization ($|\Delta\tau_{ij}| = 10\%$) for segmented markets.

4.6 Sensitivity analysis

We consider two different robustness exercises. First, we raise the aggregate market size L while maintaining the symmetry assumptions. A considerable part of the welfare gains can be attributed to the limited supply of labor and the resulting real wage increase. We relax this constraint to evaluate the impact of the labor force on the magnitude of welfare gains. Second, we vary the shape and location parameters of the respective Pareto distributions on productivity and stochastic fixed costs and check for robustness of the welfare patterns when markets are integrated.

4.6.1 The effects of an increasing labor force

We evaluate the influence of the aggregate market size (L) on the welfare gains, by assuming a labor size which is ten times the baseline labor force, i.e., we set $L = 4000$ while maintaining the

Table 4.7: Extension: Welfare Changes for $L = 4000$

	(a) Integrated markets — Wel						
	$\gamma = 0.00$	$\gamma = 0.20$	$\gamma = 0.22$	$\gamma = 0.24$	$\gamma = 0.26$	$\gamma = 0.28$	$\gamma = 0.30$
$J = 3$	2.090	2.642	2.654	2.660	2.661	2.657	2.648
$J = 4$	1.965	2.581	2.594	2.601	2.602	2.597	2.586
$J = 6$	1.798	2.485	2.500	2.507	2.508	2.503	2.490
$J = 8$	1.687	2.410	2.426	2.435	2.436	2.430	2.416
$J = 10$	1.651	2.495	2.516	2.527	2.528	2.520	2.503
	(b) Integrated markets — $\Delta Wel^{(\lvert\Delta\tau_{ij}\rvert=10\%)}$						
$J = 3$	0.58%	0.36%	0.34%	0.33%	0.32%	0.33%	0.33%
$J = 4$	1.26%	0.66%	0.63%	0.62%	0.61%	0.62%	0.63%
$J = 6$	2.34%	1.19%	1.15%	1.13%	1.12%	1.13%	1.12%
$J = 8$	3.11%	1.63%	1.58%	1.56%	1.55%	1.56%	1.59%
$J = 10$	3.99%	2.29%	2.30%	2.20%	2.19%	2.21%	2.25%
	(c) Segmented markets — Wel						
$J = 3$	2.090	2.632	2.645	2.651	2.652	2.647	2.638
$J = 4$	1.965	2.561	2.574	2.581	2.582	2.577	2.565
$J = 6$	1.798	2.445	2.461	2.469	2.469	2.463	2.450
$J = 8$	1.687	2.355	2.372	2.380	2.381	2.374	2.359
$J = 10$	1.651	2.414	2.434	2.445	2.446	2.437	2.419
	(d) Segmented markets — $\Delta Wel^{(\lvert\Delta\tau_{ij}\rvert=10\%)}$						
$J = 3$	0.58%	0.19%	0.18%	0.17%	0.17%	0.17%	0.18%
$J = 4$	1.26%	0.52%	0.49%	0.48%	0.48%	0.48%	0.50%
$J = 6$	2.34%	1.16%	1.12%	1.10%	1.10%	1.12%	1.15%
$J = 8$	3.11%	1.72%	1.68%	1.66%	1.65%	1.67%	1.71%
$J = 10$	3.99%	2.50%	2.45%	2.42%	2.42%	2.44%	2.48%

Notes: Panel (a) shows the initial welfare level for integrated markets. Panel (b) shows the welfare gains from trade liberalization ($|\Delta\tau_{ij}| = 10\%$) for integrated markets. Panel (c) shows the initial welfare level for segmented markets. Panel (d) shows the welfare gains from trade liberalization ($|\Delta\tau_{ij}| = 10\%$) for segmented markets.

restriction of symmetry and $J = \{3, 4, 6, 8, 10\}$. Labor is still shared equally across all markets and the trade cost decline is $|\Delta\tau_{ij}| = 10\%$. The results are in Table 4.7.

Compared to the baseline scenario, a larger aggregate labor force increases the initial welfare levels for both settings. Panel (a) and Panel (c) show mostly increasing levels across γ and a negative relationship with J, thus confirming the previous findings.

The higher welfare levels are the result of a corresponding increase in the number of domestic varieties, as depicted in Table 4.10 (see Appendix 4.B). After trade costs have declined, the patterns are similar and, in particular, the gains are higher for integrated market. However, the magnitude is smaller compared to the baseline findings. The intuition for the smaller size is the decreasing competition for labor and the smaller adjustment in the real wages, i.e., welfare translates into a smaller percentage change. While consumers benefit from more varieties, they confront a decreasing number of domestic varieties, irrespective of the market setting (see Table 4.11 in Appendix 4.B).

4.6.2 Robustness results for parameters of the Pareto distribution

To evaluate the sensitivity of our findings concerning parameter values, we conduct robustness checks for the set of shape parameters (α, β) as well as the respective set of location parameters (a, b). We restrict the attention to the magnitude of the welfare gains for integrated markets, considering the baseline market size ($J = 4$), and the trade cost reduction ($|\Delta\tau_{ij}| = 10\%$).

Table 4.12 in Appendix 4.B shows the respective results. According to Panel (a) and Panel (b), the welfare gains are robust to different choices of the location parameters a, while for b the gains increase between zero-returns and positive return. On the other hand, conditional on $\gamma > 0$, the pattern is similar to the baseline scenario.

Concerning the shape parameters, the patterns are similar. If we choose $\alpha = 2$, the gains are approximately half the size of the baseline case, and there is an increasing pattern between $\gamma = 0$ and $\gamma > 0$. The choice $\beta = 3$ leads to a monotone (increasing) pattern for positive returns, although the magnitude of the gains is quite similar for intermediate values of the returns and owed to the non-linearity of the model. We conclude that overall, the observed patterns and magnitudes are robust to different choices of the respective location parameters. Conditional on having positive returns, the welfare gains are similar along the distribution of γ. However, whether the percentage changes are larger for $\gamma = 0$ compared to $\gamma > 0$ or not, depends on the parameter choice.

4.7 Conclusion

The key objective of this paper is to evaluate the importance of interdependent market entry on welfare in a heterogeneous firm model. We capture market integration by allowing firms to adopt more advanced technologies to lower their marginal costs in producing a distinct variety of a single good. The optimal investment choice affects firms in their pricing and export decision and is itself a function of the market entry concerning all markets. This leads to interdependence in the sense that market entry concerning one market depends on market entry regarding all other markets.

Given that the objective function depends on the respective market entries, we need to ensure a continuous and well-defined relationship. Novel stochastic fixed costs introduce a probabilistic interpretation of market entry rather than the binary choice and allow to derive optimality conditions.

In our quantitative exercise, we quantify the impact of market interdependence on welfare conditional on scenarios of exogenous trade liberalization. The main finding is that the welfare gains are higher under market integration than under segmented markets, with market-specific innovation. Intuitively, the technology usable by firm ϕ for a specific market is higher if markets are integrated, leading to both higher initial welfare levels and respective gains.

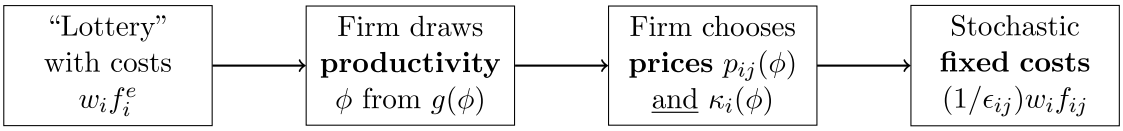
In both settings, the welfare gains are decreasing in the respective returns and increase in the number of destination markets. To reach this conclusion, we take into account the firm-specific effects. First, we show that investment returns positively affect investment levels, export probabilities, and expected aggregate profits. Given the additional demand for labor, there is a shifting of resources to more productive firms by adding a component to the selection effect by Melitz (2003).

Second, we determine the relevance of market interdependence, evaluating how a higher number of destination markets affect firm-specific choices when holding aggregate market size constant. In particular, a higher number of markets lowers the labor force per market, leading to stronger competition for labor and higher aggregate market entry costs. As a result, the optimal investment, the related market entry probability, and the number of varieties all decrease in the number of markets.

The main takeaway is that market interdependence and the number of markets both display important features when discussing the optimal investment choice of heterogeneous firms. By design, our model has paved the way to capture market interdependence, and besides, it provides an easily applicable and general framework that can be extended to other scenarios where decisions create heterogeneity in how heterogeneous firms interact across markets.

Appendix 4.A Model derivations

Figure 4.7: Structure of Events



Notes: This figure displays the structure of events from participating in the lottery up to the realization of the stochastic fixed costs.

Figure 4.7 displays the structure of events. Importantly, firms participate in a lottery at cost $w_i f_i^e$ to learn their productivity level ϕ (Step 1). Second, the obtain their firm productivity ϕ from a Pareto distribution $g(\phi)$, which is identical for all markets and perfect information (Step 2). In the next step, firms choose optimal market-specific price levels and decide on the optimal level of technology adoption (Step 3). Finally, firms receive the market-specific fixed costs (ϵ_{ij}) from a second Pareto distribution deciding on market entry (Step 4). If a firm could readjust its optimal pricing after realizing the market entry costs, the export choice would again reduce to a binary choice with a non-differentiable objective function.

We consider representative households that derive utility from consuming different varieties $\omega \in \Omega_{ij}$ of a single good. A household in country j maximizes utility U_j subject to the budget constraint. Income is generated from the inelastic supply of labor generating $Y_j = w_j L_j$.

$$\max_{q_{ij}} U_j = \left(\sum_{i \in j} \int_{\Omega_{ij}} q_{ij}(\phi)^{\frac{\sigma-1}{\sigma}} \right)^{\sigma/(\sigma-1)} \quad \text{s.t.} \quad \sum_{i \in J} \int_{\Omega_{ij}} p_{ij}(\phi) q_{ij}(\phi) d\phi = w_j L_j \tag{4.A.1}$$

Based on the Lagrangian function, we can derive the 'first-order conditions' (FOC):

$$\frac{\partial L}{\partial q_{ij}(\phi)} = \left(\sum_{j} \int_{\Omega_{ij}} q_{ij}(\phi)^{\frac{\sigma-1}{\sigma}} d\phi \right)^{\frac{1}{\sigma-1}} q_{ij}(\phi)^{-\frac{1}{\sigma}} = \lambda p_{ij}(\phi) \tag{4.A.2}$$

$$\frac{\partial L}{\partial \lambda} = \sum_{i \in J} \int_{\Omega_{ij}} p_{ij}(\omega) q_{ij}(\omega) d\omega = w_j L_j \tag{4.A.3}$$

From the FOCs, we have for any i, i' and $j \in J$

$$\frac{q_{ij}^{-\frac{1}{\sigma}}(\phi)}{q_{ij}^{-\frac{1}{\sigma}}(\phi)} = \frac{p_{ij}(\phi)}{p_{i'j}(\phi)} \Longleftrightarrow 1 = \frac{p_{ij}(\phi)^{\sigma} q_{ij}(\phi)}{p_{i'j}(\phi) q_{i'j}(\phi)} \tag{4.A.4}$$

Summing over all $i' \in J$, we have

$$\begin{aligned} \sum_{i' \in J} \int_{\Omega_{ij}} p_{i'j}(\phi) q_{i'j}(\phi) d\phi &= q_{i'j}(\phi) p_{i'j}(\phi)^{\sigma} \sum_{i' \in J} \int_{\Omega_{ij}} p_{i'j}^{1-\sigma}(\phi) d\phi \\ Y_j &= q_{i'j}(\phi) p_{i'j}^{\sigma}(\phi) P_j^{1-\sigma} \\ Y_j &= q_{ij}(\phi) p_{ij}^{\sigma}(\phi) P_j^{1-\sigma}, \end{aligned} \tag{4.A.5}$$

where in the last step, we consider the specific case with $i' = i$ and replace the expression $Y_j = w_j L_j$. Rearranging for the optimal demand $q_{ij}(\phi)$, we obtain:

$$q_{ij}(\phi) = \frac{p_{ij}^{-\sigma}(\phi)}{P_j^{1-\sigma}} Y_j \tag{4.A.6}$$

The aggregate CES consumer price is given by $P_j = \left(\sum_j \int_{\Omega_{ij}} p_{ij}(\omega) d\omega\right)^{\frac{1}{1-\sigma}}$. Throughout, we abbreviate $p_{ij}(\phi, \kappa_i(\phi))$ by $p_{ij}(\phi)$.

Derivation of the profit maximizing price $p_{ij}(\phi)$

To determine the derivative of $V_{ij}^*(\phi)$, recall from the main text that we have defined $V_{ij}(\phi) \equiv \frac{1}{\sigma}\left(\frac{\sigma}{\sigma-1}\frac{w_i \tau_{ij}}{\phi}\right)^{1-\sigma} \frac{Y_j P_j^{\sigma-1}}{w_i f_{ij}}$ and second, $V_{ij}^*(\kappa_i(\phi)) \equiv (1+\kappa_i(\phi))^{\gamma} V_{ij}(\phi)$. Then, the partial derivative $\partial V_{ij}^*(\kappa_i(\phi))/\partial \kappa_i(\phi)$ can be written as

$$\left(V_{ij}^*\right)' = \frac{1}{\sigma}\left(\frac{\sigma}{\sigma-1} w_i \tau_{ij}\right)^{1-\sigma} \frac{Y_j P_j^{\sigma-1}}{w_i f_{ij}} \phi^{\sigma-1} \gamma \left(1+\kappa_i(\phi)\right)^{\gamma-1}. \tag{4.A.7}$$

The aim is to derive the optimal market-specific pricing rule $p_{ij}(\phi)$. To do so, we optimize the bilateral profit function $\pi_{ij}(\phi)$ with respect to the market-specific price level. First, we note that

$$\pi_{ij}(\phi) = p_{ij}(\phi) q_{ij}(\phi) - c_{ij}(\phi), \tag{4.A.8}$$

and define the market-specific costs $c_{ij}(\phi)$

$$c_{ij}(\phi) \equiv q_{ij}(\phi) c + \frac{1}{\epsilon_{ij}} w_i f_{ij}. \tag{4.A.9}$$

Next, we plug in the terms for household demand $q_{ij}(\phi) = p_{ij}^{-\sigma}(\phi) Y_t P_j^{\sigma-1}$, and define the term c as the effective costs of producing one unit of the final good.

$$c \equiv \frac{w_i \tau_{ij}}{(1+\kappa_i(\phi))^{\gamma/(\sigma-1)} \phi}. \tag{4.A.10}$$

This procedure yields the final expression for bilateral profits, which can be reformulated as:

$$\pi_{ij}(\phi) = \left[p_{ij}^{1-\sigma}(\phi) Y_j P_j^{\sigma-1}\right] - \left[p_{ij}^{-\sigma}(\phi) Y_j P_j^{\sigma-1} \frac{w_i \tau_{ij}}{(1+\kappa_i(\phi))^{\gamma/(\sigma-1)} \phi} + \frac{1}{\epsilon_{ij}} w_i f_{ij}\right] \tag{4.A.11}$$

The first-order condition then reads:

$$\frac{\partial \pi_{ij}(\phi)}{\partial p_{ij}(\phi)} = (1-\sigma) p_{ij}^{-\sigma}(\phi) \stackrel{!}{=} -\sigma \frac{w_i \tau_{ij}}{(1+\kappa_i(\phi))^{\gamma/(\sigma-1)} \phi} p_{ij}^{-\sigma-1}(\phi)$$

$$p_{ij}(\phi) \stackrel{!}{=} \frac{\sigma}{\sigma-1} \frac{w_i \tau_{ij}}{\phi} \left(1+\kappa_i(\phi)\right)^{\frac{\gamma}{1-\sigma}} \tag{4.A.12}$$

We obtain a pricing rule, which follows the markup over marginal cost relationship in the literature (e.g., Krugman, 1980; Melitz, 2003). The equation shows that the price level remains a decreasing function of the firm's ex-ante productivity level ϕ but it is also decreasing in the technology level. To see this, notice that $\gamma/(1-\sigma) < 0$, meaning that the higher technology investment lowers the unit cost of production and hence, lowers the price level given the wage rate (w_i) and the bilateral trade costs (τ_{ij}). After deriving the optimal price rule, we use the pricing expression back in the market-specific profit equation:

$$\pi_{ij}(\phi) = \left[p_{ij}^{1-\sigma}(\phi) - \frac{w_i \tau_{ij}}{(1+\kappa_i(\phi))^{\gamma/(\sigma-1)}\phi} p_{ij}^{-\sigma}(\phi)\right] Y_j P_j^{1-\sigma} - \frac{1}{\epsilon_{ij}} w_i f_{ij} \tag{4.A.13}$$

Plugging in the term for p_{ij} and multiplying by $(\sigma - 1/\sigma - 1)$ yields

$$\begin{aligned}
\pi_{ij}(\phi) = & \left[\left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma} \left(\frac{w_i\tau_{ij}}{\phi}\right)^{1-\sigma} (1+\kappa_i(\phi))^{\gamma} - \frac{w_i\tau_{ij}}{(1+\kappa_i(\phi))^{\frac{\gamma}{\sigma-1}}\phi} \left(\frac{\sigma}{\sigma-1}\right)^{-\sigma} \cdot \right. \\
& \left. \left(\frac{w_i\tau_{ij}}{\phi}\right)^{-\sigma} (1+\kappa_i(\phi))^{-\frac{\gamma\sigma}{1-\sigma}}\right] Y_j P_j^{1-\sigma} - \frac{1}{\epsilon_{ij}} w_i f_{ij} \\
= & \left[\left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma} \left(\frac{w_i\tau_{ij}}{\phi}\right)^{1-\sigma} (1+\kappa_i(\phi))^{\gamma} - \left(\frac{\sigma}{\sigma-1}\right)^{-\sigma} - \left(\frac{w_i\tau_{ij}}{\phi}\right)^{1-\sigma} \right. \\
& \left. (1+\kappa_i(\phi))^{\gamma\frac{(1-\sigma)}{(1-\sigma)}}\right] Y_j P_j^{1-\sigma} - \frac{1}{\epsilon_{ij}} w_i f_{ij} \\
= & \left(\frac{w_i\tau_{ij}}{\phi}\right)^{1-\sigma} (1+\kappa_i(\phi))^{\gamma} \left[\left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma} - \left(\frac{\sigma}{\sigma-1}\right)^{-\sigma}\right] Y_j P_j^{1-\sigma} - \frac{1}{\epsilon_{ij}} w_i f_{ij} \\
= & \left(\frac{w_i\tau_{ij}}{\phi}\right)^{1-\sigma} (1+\kappa_i(\phi))^{\gamma} \left[\frac{\sigma^{1-\sigma}}{(\sigma-1)^{1-\sigma}} - \frac{\sigma^{1-\sigma}-\sigma^{-\sigma}}{(\sigma-1)^{1-\sigma}}\right] Y_j P_j^{1-\sigma} - \frac{1}{\epsilon_{ij}} w_i f_{ij} \\
= & \left(\frac{w_i\tau_{ij}}{\phi}\right)^{1-\sigma} (1+\kappa_i(\phi))^{\gamma} \left[\frac{\sigma^{-\sigma}}{(\sigma-1)^{1-\sigma}}\right] Y_j P_j^{1-\sigma} - \frac{1}{\epsilon_{ij}} w_i f_{ij}.
\end{aligned} \tag{4.A.14}$$

Rewriting the term $\left[\frac{\sigma^{-\sigma}}{(\sigma-1)^{1-\sigma}}\right] = \left[\frac{\sigma^{-1}\sigma^{1-\sigma}}{(\sigma-1)^{1-\sigma}}\right] = \left[\frac{1}{\sigma}\left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma}\right]$, we obtain the final relationship

$$\pi_{ij}(\phi) = \frac{1}{\sigma}\left(\frac{\sigma}{\sigma-1}\frac{w_i\tau_{ij}}{\phi}\right)^{1-\sigma} (1+\kappa_i(\phi))^{\gamma} Y_j P_j^{\sigma-1} - \frac{1}{\epsilon_{ij}} w_i f_{ij} \tag{4.A.15}$$

It is immediate that a sufficient condition for firm i to export into market j is

$$\begin{aligned}
\pi_{ij}(\phi) = \frac{1}{\sigma}\left(\frac{\sigma}{\sigma-1}\frac{w_i\tau_{ij}}{\phi}\right)^{1-\sigma} (1+\kappa_i(\phi))^{\gamma} Y_j P_j^{\sigma-1} - \frac{1}{\epsilon_{ij}} w_i f_{ij} \geq 0 \\
\frac{w_i f_{ij}}{\frac{1}{\sigma}\left(\frac{\sigma}{\sigma-1}\frac{w_i\tau_{ij}}{\phi}\right)^{1-\sigma} (1+\kappa_i(\phi))^{\gamma} Y_j P_j^{\sigma-1}} \leq \epsilon_{ij}
\end{aligned} \tag{4.A.16}$$

This condition provides a lower bound for the stochastic fixed costs component. In the following, we use the probability term to determine the cumulative distribution function

$$G(\epsilon_{ij}) = 1 - \left(\frac{a}{\epsilon_{ij}}\right)^{\alpha} \quad \text{and} \quad g(\epsilon_{ij}) = \frac{\alpha a^{\alpha}}{\epsilon_{ij}^{\alpha+1}}. \tag{4.A.17}$$

We can derive the probability for a firm with productivity ϕ to serve market j by defining

$$\chi_{ij}(\phi) \equiv \Pr(\epsilon_{ij} \geq \epsilon_{ij}^*) = 1 - G\left(\frac{1}{V_{ij}^*}\right) = 1 - \left(1 - \frac{a^{\alpha}}{\epsilon_{ij}^{*\alpha}}\right) = a^{\alpha}\left(V_{ij}^*\right)^{\alpha}. \tag{4.A.18}$$

This equation shows that the export probability is a function of productivity and investment. Spelled out, productivity shows up in the numerator, thus indicating that more productive firms are also more likely to export. A related effect comes through the incentive of more productive firms to also improve productivity. Since $\kappa_i(\phi)$ is increasing in the productivity level ϕ, it follows that more productive firms also have a higher probability to serve market j. This argument is in favor of decreasing marginal cost (Antràs et al., 2017).

Derivation of the expected aggregate profits $\mathbb{E}_\epsilon(\Pi_i(\kappa_i(\phi)))$

We start by recalling that aggregate profits are the sum over the region-specific profits. Formally,

$$\begin{aligned}\Pi_i(\phi) &= \left\{\sum_j \chi_{ij}(\phi)\pi_{ij}(\phi)\right\} - \eta_i\kappa_i(\phi)w_i \\ &= \sum_j \chi_{ij}(\phi)\left[p_{ij}(\phi)q_{ij}(\phi) - q_{ij}(\phi)\frac{w_i\tau_{ij}}{\phi} - \frac{1}{\epsilon_{ij}}w_i f_{ij}\right] - \eta_i\kappa_i(\phi)w_i \end{aligned} \tag{4.A.19}$$

In the following, we use $V_{ij}^* = (1+\kappa_i(\phi))^\gamma\phi^{\sigma-1}V_{ij}$ and abbreviate $V_{ij}^*(\phi)$ by V_{ij}^*.

$$\begin{aligned}\mathbb{E}_\epsilon[\Pi_i(\kappa_i(\phi))] &= \mathbb{E}_\epsilon\sum_j \chi_{ij}(\phi)\left(V_{ij}^* w_i f_{ij} - \frac{1}{\epsilon_{ij}}w_i f_{ij}\right) - \eta_i\kappa_i(\phi)w_i \\ &= \sum_j \chi_{ij}(\phi)\left(V_{ij}^* w_i f_{ij} - \mathbb{E}_\epsilon\left[\frac{1}{\epsilon_{ij}}|\epsilon \geq \frac{1}{V_{ij}^*}\right]w_i f_{ij}\right) - \eta_i\kappa_i(\phi)w_i \end{aligned} \tag{4.A.20}$$

To find an expression for $\mathbb{E}_\epsilon\left[(1/\epsilon_{ij})|\epsilon_{ij} \geq (1/V_{ij}^*)\right]$, we recall that

$$g(\epsilon_{ij}|\epsilon_{ij} \geq \epsilon_{ij}^*)) = \frac{g(\epsilon_{ij})}{1-G(\ln(\epsilon_{ij}^*))} = \frac{\alpha a^\alpha}{\epsilon_{ij}^{\alpha+1}}\left(\frac{a^\alpha}{\epsilon^{*\alpha}}\right)^{-1} = \frac{\alpha}{\epsilon_{ij}^{\alpha+1}}\left(V_{ij}^*\right)^{-\alpha} \tag{4.A.21}$$

In the next step, we derive a simplified expression for the expected aggregate profits. Therefore, we also use $\chi_{ij}(\phi) = \Pr(\epsilon_{ij} = \epsilon_{ij}^*) = a^\alpha\left(V_{ij}^*\right)^\alpha$. Specifically,

$$\mathbb{E}_\epsilon[\Pi_i(\kappa_i(\phi))] = \sum_j \chi_{ij}(\phi)\left[V_{ij}^* w_i f_{ij} - \left(\int_{\epsilon_{ij}^*}^\infty \frac{1}{\epsilon_{ij}}\frac{\alpha}{\epsilon_{ij}^{\alpha+1}}\left(V_{ij}^*\right)^{-\alpha}d\epsilon\right)w_i f_{ij}\right] \tag{4.A.22}$$

We can further simplify this expression by using $\chi_{ij}(\phi) = a^\alpha\left(V_{ij}^*\right)^\alpha$ to finally obtain

$$\begin{aligned}\mathbb{E}_\epsilon(\Pi_i(\kappa_i(\phi))) &= \sum_j \chi_{ij}(\phi)\left[V_{ij}^* w_i f_{ij} - w_i f_{ij}\left(V_{ij}^*\right)^{-\alpha}\alpha\left[\frac{1}{-\alpha-1}e^{-\alpha-1}\right]_{1/V_{ij}^*}^\infty\right] - \eta_i\kappa_i(\phi)w_i \\ &= \sum_j \chi_{ij}(\phi)\left[V_{ij}^* w_i f_{ij} - w_i f_{ij}\left(V_{ij}^*\right)^{-\alpha}\alpha\left(0 + \frac{1}{1+\alpha}\right)\right] - \eta_i\kappa_i(\phi)w_i \\ &= \sum_j a^\alpha V_{ij}^{*\alpha}\left[V_{ij}^* w_i f_{ij} - \frac{\alpha}{1+\alpha}w_i f_{ij}\left(V_{ij}^*\right)^{-\alpha}\right] - \eta_i\kappa_i(\phi)w_i \end{aligned} \tag{4.A.23}$$

Derivation of innovation under integration $\kappa_i(\phi)$

We can further simplify the previous expression

$$\mathbb{E}_\epsilon(\Pi_i(\kappa_i(\phi))) = \sum_j a^\alpha \left(V_{ij}^*\right)^\alpha \left[\frac{1}{1+\alpha} V_{ij}^* w_i f_{ij}\right] - \eta_i \kappa_i(\phi) w_i \qquad (4.A.24)$$

$$= \sum_j \left[\frac{1}{1+\alpha}\right] a^\alpha \left(V_{ij}^*\right)^{\alpha+1} w_i f_{ij} - \eta_i \kappa_i(\phi) w_i$$

The first-order condition then reads:

$$\frac{\partial \mathbb{E}_\epsilon(\Pi_i(\kappa_i(\phi))}{\partial \kappa_i(\phi)} = a^\alpha \sum_j \left[\left(V_{ij}^*\right)^\alpha \left(V_{ij}^*\right)'\right] w_i f_{ij} - \eta_i w_i \stackrel{!}{=} 0$$

$$= \sum_j \Pr(\epsilon_{ij} > \epsilon_{ij}^*) \left(V_{ij}^*\right)' w_i f_{ij} \stackrel{!}{=} \eta_i w_i \qquad (4.A.25)$$

We interpret this result as follows: in equilibrium, the benefits from spending a marginal unit on technology is equal to its costs expressed as the wage payment $\eta_i w_i$. Recall that the functions $V_{ij}^*(\kappa_i(\phi))$ and $V_{ij}^{'*}(\kappa_i(\phi))$ are defined as:

$$V_{ij}^*(\kappa_i(\phi)) = \frac{1}{\sigma}\left(\frac{\sigma}{\sigma-1} w_i f_{ij}\right)^{1-\sigma} \frac{Y_j P_j^{\sigma-1}}{w_i f_{ij}} \phi^{\sigma-1} \left(1+\kappa_i(\phi)\right)^\gamma \qquad (4.A.26)$$

$$V_{ij}^{*'}(\kappa_i(\phi)) = \frac{1}{\sigma}\left(\frac{\sigma}{\sigma-1} w_i f_{ij}\right)^{1-\sigma} \frac{Y_j P_j^{\sigma-1}}{w_i f_{ij}} \phi^{\sigma-1} \gamma \left(1+\kappa_i(\phi)\right)^{\gamma-1} \qquad (4.A.27)$$

We can simplify the expressions further by writing the first-order condition as:

$$\sum_j \frac{a^\alpha}{1+\alpha} \gamma(\alpha+1) \left[\frac{1}{\sigma}\left(\frac{\sigma}{\sigma-1}\frac{w_i \tau_{ij}}{\phi}\right)^{1-\sigma} \frac{Y_j P_j^{\sigma-1}}{w_i f_{ij}}\right]^{\alpha+1} \left(1+\kappa_i(\phi)\right)^{\gamma(\alpha+1)-1} w_i f_{ij} = \eta_i w_i \qquad (4.A.28)$$

We next rewrite the expression in terms of $\chi_{ij}(\phi)$ and V_{ij}^*, or equivalently $a^\alpha \left(V_{ij}^*\right)^{\alpha+1}$, multiply by "one" $[1 = H_i/H_i]$ to restore the respective terms

$$\sum_j \frac{a^\alpha}{1+\alpha} \gamma(\alpha+1) \left[\frac{1}{\sigma}\left(\frac{\sigma}{\sigma-1}\frac{w_i \tau_{ij}}{\phi}\right)^{1-\sigma} \frac{Y_j P_j^{\sigma-1}}{w_i f_{ij}}\right]^{\alpha+1} \left(1+\kappa_i(\phi)\right)^{\gamma(\alpha+1)-1} \frac{H_i}{H_i} w_i f_{ij} = \eta_i w_i, \qquad (4.A.29)$$

where $H_i = (1+\kappa_i(\phi))^{\gamma(\alpha+1)}$ which can be rearranged accordingly

$$\sum_j \gamma \left[\frac{1}{\sigma}\left(\frac{\sigma}{\sigma-1}\frac{w_i \tau_{ij}}{\phi}\right)^{1-\sigma} \frac{Y_j P_j^{\sigma-1}}{w_i f_{ij}}\right]^{\alpha+1} \left(1+\kappa_i(\phi)\right)^{\gamma(\alpha+1)} \frac{\left(1+\kappa_i(\phi)\right)^{\gamma(\alpha+1)-1}}{\left(1+\kappa_i(\phi)\right)^{\gamma(\alpha+1)}} f_{ij} = \eta_i$$

$$\sum_j \gamma \chi_{ij}(\phi) V_{ij}^* \frac{\left(1+\kappa_i(\phi)\right)^{\gamma(\alpha+1)-1}}{\left(1+\kappa_i(\phi)\right)^{\gamma(\alpha+1)}} f_{ij} = \eta_i$$

$$\left(1+\kappa_i(\phi)\right)^{-1} \sum_j \gamma \chi_{ij}(\phi) V_{ij}^* f_{ij} = \eta_i \qquad (4.A.30)$$

Solving for the optimal investment level then yields:

$$\kappa_i^*(\phi) = \frac{\gamma}{\eta_i} \sum_j \chi_{ij}(\phi) V_{ij}^* f_{ij} \tag{4.A.31}$$

To determine the trade share and the gravity equation, first note that country j spends the following amount on the variety produced by firm ϕ in country i:

$$x_{ij}(\phi) = \frac{p_{ij}(\phi)^{1-\sigma}}{P_j^{1-\sigma}} Y_j = \frac{p_{ij}(\phi)^{1-\sigma}}{P_j^{1-\sigma}} E_j$$

Aggregate trade flows. The next step is to aggregate the bilateral flows across all domestic firms and quantify the aggregate trade flows between markets i and j. This delivers

$$X_{ij} \equiv \int_{\Omega_i} x_{ij}(\omega) d\omega = Y_j P_j^{\sigma-1} N_i \int_{\underline{\phi}_i}^{\infty} \chi_{ij}(\phi) p_{ij}(\phi)^{1-\sigma} f(\phi) d\phi \tag{4.A.32}$$

Given the aggregate trade flows, the bilateral trade share (λ_{ij}) is the fraction of goods (or expenditures) market j spends on goods from market i (Costinot and Rodríguez-Clare, 2014).

$$\begin{aligned}
\lambda_{ij} = \frac{X_{ij}}{\sum_k X_{kj}} &= \frac{N_i Y_j P_j^{\sigma-1} \int_{\underline{\phi}_i}^{\infty} \chi_{ij}(\phi) p_{ij}(\phi)^{1-\sigma} f(\phi) d\phi}{\sum_k N_k Y_j P_j^{\sigma-1} \int_{\underline{\phi}_i}^{\infty} \chi_{kj}(\phi) p_{ik}(\phi)^{1-\sigma} f(\phi) d\phi} \\
&= \frac{Y_j P_j^{\sigma-1} N_i \int_{\underline{\phi}_i}^{\infty} \chi_{ij}(\phi) p_{ij}(\phi)^{1-\sigma} f(\phi) d\phi}{Y_j P_j^{\sigma-1} \sum_k N_k \int_{\underline{\phi}_i}^{\infty} \chi_{kj}(\phi) p_{ik}(\phi)^{1-\sigma} f(\phi) d\phi} \\
&= \frac{N_i \int_{\underline{\phi}_i}^{\infty} \chi_{ij}(\phi) p_{ij}(\phi)^{1-\sigma} f(\phi) d\phi}{\sum_k N_k \int_{\underline{\phi}_i}^{\infty} \chi_{kj}(\phi) p_{ik}(\phi)^{1-\sigma} f(\phi) d\phi} \\
&= \frac{N_i \int_{\underline{\phi}_i}^{\infty} \chi_{ij}(\phi) p_{ij}(\phi)^{1-\sigma} f(\phi) d\phi}{P_j^{1-\sigma}}
\end{aligned} \tag{4.A.33}$$

Here, X_{ij} denotes the spending of market j on goods from (exporter) i, and $\sum_k X_{kj}$ denotes the overall spending of (importer) j, i.e., $E_j = \sum_i X_{ij}$. The goods market clearing requires that spending be equal to income. Put differently, the spending $w_i L_i$ must be equal to the respective expenditures $\sum_j \lambda_{ij} w_j L_j, \forall j \in J$.

Free entry condition. The free entry condition demands that the expected aggregate profits cover all participation costs. The expected aggregate profits are given by

$$\mathbb{E}_\epsilon(\Pi_i(\phi)) = \sum_j \left(\frac{1}{\alpha+1}\right) a^\alpha \left(V_{ij}^*\right)^{\alpha+1} w_i f_{ij} - \eta_i \kappa_i(\phi) w_i. \tag{4.A.34}$$

Rewriting this expression using $a^\alpha \left(V_{ij}^*\right)^\alpha = \chi_{ij}(\phi)$, we obtain

$$\mathbb{E}_\phi(\Pi_i(\phi)) = \sum_j \int_\Phi \left[\left(\frac{1}{\alpha+1}\right) \chi_{ij}(\phi) V_{ij}^* w_i f_{ij} - \eta_i \kappa_i(\phi) w_i\right] f(\phi) d\phi \stackrel{!}{=} w_i f_i^e. \tag{4.A.35}$$

Rearranging terms yields the free entry condition as states in the main text:

$$\mathbb{E}_\phi(\Pi_i(\phi)) = \left(\frac{1}{\alpha+1}\right) \sum_j \int_\Phi \left[\chi_{ij}(\phi) V_{ij}^* w_i f_{ij} - \eta_i w_i \kappa_i(\phi)\right] f(\phi) d\phi \stackrel{!}{=} w_i f_i^e. \tag{4.A.36}$$

Contrary to the standard free entry condition, expected profits must cover the fixed market entry costs and the investment costs.

Labor market clearing condition. Labor markets must clear such that labor supply matches labor demand. Labor is used for participation in the lottery, for producing the good ω, for paying market entry costs, and finally, for covering the technology expenses. Formally,

$$l_i(\phi) = f_i^e + f_{ij} + \frac{\sum_j \chi_{ij}(\phi) q_{ij}(\phi)}{(1+\kappa_i(\phi))^{\gamma}\phi}\tau_{ij} + \eta_i\kappa_i(\phi),$$

where we abstract from trade frictions in the domestic market by normalizing $\tau_{ii} = 1$. On the other hand, for one unit of good ϕ to arrive at j, $q_{ij}(\phi)\tau_{ij}$ goods must be produced. Further, the labor market equilibrium takes into account the number of domestic firms N_i, the probability to export $\chi_{ij}(\phi)$, and the distribution of productivity $f(\phi)$:

$$\begin{aligned} L_i = N_i f_i^e + N_i \sum_j \int_{\underline{\phi}_i}^{\infty} \chi_{ij}(\phi) \frac{p_{ij}(\phi)^{-\sigma}\tau_{ij}}{(1+\kappa_i(\phi))^{\frac{\gamma}{\sigma-1}}\phi} Y_j P_j^{\sigma-1} f(\phi) d\phi + N_i\eta_i \int_{\underline{\phi}_i} \kappa_i(\phi) f(\phi) d\phi \\ + N_i \sum_j \int_{\underline{\phi}_i}^{\infty} \chi_{ij}(\phi) f_{ij} f(\phi) d\phi, \end{aligned} \tag{4.A.37}$$

Derivation of innovation under segmentation $\kappa_{ij}(\phi)$

When markets are segmented, we assume that every firm invests market-specifically, κ_{ij}. The corresponding expected market-specific profits conditional on exporting then read as follows:

$$\mathbb{E}_{\epsilon}(\Pi_{ij}(\kappa_{ij}(\phi))) = a^{\alpha}\left(V_{ij}^*\right)^{\alpha}\left[\frac{1}{1+\alpha}V_{ij}^* w_i f_{ij}\right] - \eta_i\kappa_i(\phi) w_i \tag{4.A.38}$$

$$= \left[\frac{1}{1+\alpha}\right] a^{\alpha}\left(V_{ij}^*\right)^{\alpha+1} w_i f_{ij} - \eta_i\kappa_i(\phi) w_i \tag{4.A.39}$$

Based on this equation, we can rewrite the equations in terms of κ_{ij}.

$$\mathbb{E}_{\epsilon}(\Pi_{ij}(\kappa_{ij}(\phi))) = \frac{1}{1+\alpha} a^{\alpha}\left[\frac{1}{\sigma}\left(\frac{\sigma}{\sigma-1}\frac{w_i\tau_{ij}}{\phi}\right)^{1-\sigma}(1+\kappa_{ij})^{\gamma} Z_j\right]^{\alpha+1} w_i f_{ij} - \eta_i w_i \kappa_i, \tag{4.A.40}$$

where we have abbreviated $Z_j = \frac{Y_j P_j^{\sigma-1}}{w_i f_{ij}}$. The optimality condition with respect to the optimal innovation level, then yields after some simple algebra

$$(1+\kappa_{ij})^* = \left[\frac{\gamma a^{\alpha}\left[\frac{1}{\sigma}\left(\frac{\sigma}{\sigma-1}\frac{w_i\tau_{ij}}{\phi}\right)^{1-\sigma}\frac{Y_j P_j^{\sigma-1}}{w_i f_{ij}}\right]^{\alpha+1} w_i f_{ij}}{\eta_i w_i}\right]^{1/(1-\gamma\alpha-\gamma)} \tag{4.A.41}$$

Derivation of the effective productivity $\xi_i(\phi)$

We derive an expression for the composite productivity. The average price level is given by

$$\int_{\omega_i} p_{ij}(\omega)^{1-\sigma} d\omega = \int_0^\infty \chi_{ij}(\phi) N_i \left(\frac{\sigma}{\sigma-1} \frac{w_i \tau_{ij}}{\phi} (1+\kappa_i(\phi))^{\frac{\gamma}{\sigma-1}} \right)^{1-\sigma} f(\phi) d\phi \quad (4.A.42)$$

$$= \left(\frac{\sigma}{\sigma-1} w_i \tau_{ij} \right)^{1-\sigma} N_i \int_0^\infty \chi_{ij}(\phi) \phi^{\sigma-1} (1+\kappa_i(\phi))^\gamma f(\phi) d\phi, \quad (4.A.43)$$

where the average productivity of producers selling from market i to j is given by

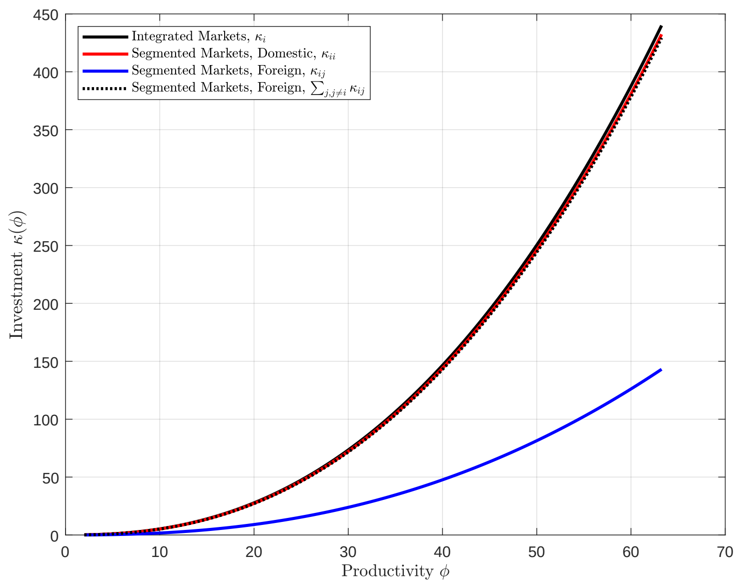
$$\tilde{\phi}_{ij} = \left(\int_0^\infty \chi_{ij}(\phi) \phi^{\sigma-1} (1+\kappa_i(\phi))^\gamma f(\phi) d\phi \right)^{\frac{1}{\sigma-1}} \quad (4.A.44)$$

Note that the average productivity is increasing in the probability to export χ_{ij}, the initial productivity ϕ and the investment level κ_i. To evaluate the composite productivity, we do not calculate the average productivity of firms serving market j, but restrict to evaluating the term

$$\xi_i(\phi) = \phi(1+\kappa_i(\phi))^{\gamma/(\sigma-1)} \quad (4.A.45)$$

Appendix 4.B Counterfactual analysis

Figure 4.8: Investment Level κ (After Liberalization)



Notes: This figure shows the optimal investment level for integrated markets ($\kappa_i(\phi)$, solid black line) and segmented markets, in particular, the domestic investment ($\kappa_{ii}(\phi)$, red line), the market-specific foreign investment ($\kappa_{ij}(\phi)$, blue line) and the sum of all foreign investments ($\sum_{j,j\neq i} \kappa_{ij}(\phi)$, dotted black line). All results are for $\gamma = 0.30$, $J = 4$ and after trade liberalization.

Table 4.8: Number of Firms N_i (Hundreds) — Segmented Markets

	$\gamma = 0.00$	$\gamma = 0.20$	$\gamma = 0.22$	$\gamma = 0.24$	$\gamma = 0.26$	$\gamma = 0.28$	$\gamma = 0.30$
	(a) Number of firms						
Baseline	6.17	6.17	6.10	6.03	5.97	5.92	5.88
	(b) Number of firms — Markets J						
$J = 3$	10.34	8.89	8.73	8.61	8.53	8.48	8.46
$J = 4$	6.17	6.17	6.10	6.03	5.97	5.92	5.88
$J = 6$	2.94	3.47	3.45	3.42	3.39	3.35	3.31
$J = 8$	1.72	2.23	2.22	2.22	2.18	2.16	2.12
$J = 10$	1.14	1.70	1.70	1.69	1.68	1.66	1.62

Notes: This table shows the number of firms for segmented markets. Panel (a) shows the results for the baseline scenario, Panel (b) considers different numbers of markets J. The respective numbers are in hundreds.

Table 4.9: Number of Firms N_i (Hundreds) — $|\Delta\tau_{ij}| = 10\%$

	$\gamma = 0.00$	$\gamma = 0.20$	$\gamma = 0.22$	$\gamma = 0.24$	$\gamma = 0.26$	$\gamma = 0.28$	$\gamma = 0.30$
	(a) Number of firms — Integrated markets						
$J = 3$	8.78	6.34	6.20	6.10	6.04	6.03	6.07
$J = 4$	5.23	4.31	4.23	4.17	4.13	4.12	4.13
$J = 6$	2.52	2.43	2.40	2.37	2.35	2.34	2.33
$J = 8$	1.50	1.59	1.57	1.57	1.55	1.54	1.53
$J = 10$	1.01	1.27	1.27	1.26	1.25	1.24	1.23
	(b) Number of firms — Segmented markets						
$J = 3$	8.78	7.42	7.29	7.19	7.11	7.08	7.06
$J = 4$	5.23	5.08	5.01	4.95	4.90	4.86	4.83
$J = 6$	2.52	2.85	2.83	2.80	2.78	2.75	2.72
$J = 8$	1.50	1.85	1.84	1.82	1.81	1.79	1.76
$J = 10$	1.01	1.44	1.44	1.43	1.42	1.40	1.37

Notes: This table shows the number of firms after trade costs have declined by $|\Delta\tau_{ij}| = 10\%$. Panel (a) shows the results for the integrated markets, Panel (b) for segmented markets. The respective numbers are in hundreds.

Table 4.10: Number of Firms N_i (Hundreds) — Robustness

	$\gamma = 0.00$	$\gamma = 0.20$	$\gamma = 0.22$	$\gamma = 0.24$	$\gamma = 0.26$	$\gamma = 0.28$	$\gamma = 0.30$
(a) Number of firms — Integrated markets							
$J = 3$	24.16	7.68	7.33	7.13	7.06	7.14	7.36
$J = 4$	16.30	6.02	5.76	5.61	5.56	5.61	5.76
$J = 6$	9.12	4.12	3.96	3.87	3.83	3.86	3.94
$J = 8$	5.96	3.07	2.97	2.90	2.88	2.89	2.94
$J = 10$	4.68	3.08	2.99	2.94	2.91	2.92	2.95
(b) Number of firms — Segmented markets							
$J = 3$	24.16	9.32	8.95	8.72	8.64	8.70	8.91
$J = 4$	16.30	7.53	7.26	7.09	7.03	7.06	7.20
$J = 6$	9.12	5.30	5.14	5.04	4.99	5.00	5.06
$J = 8$	5.96	4.00	3.90	3.82	3.79	3.78	3.81
$J = 10$	4.68	3.96	3.89	3.83	3.80	3.78	3.78

Notes: This table shows the number of firms for the robustness exercise with $L = 4000$. Panel (a) displays the values for integrated markets. Panel (b) shows the results for segmented markets. The respective numbers are in hundreds.

Table 4.11: Number of Firms N_i (Hundreds) — Robustness for $|\Delta\tau_{ij}| = 10\%$

	$\gamma = 0.00$	$\gamma = 0.20$	$\gamma = 0.22$	$\gamma = 0.24$	$\gamma = 0.26$	$\gamma = 0.28$	$\gamma = 0.30$
(a) Number of firms — Integrated markets							
$J = 3$	20.43	6.43	6.14	5.96	5.91	5.97	6.16
$J = 4$	13.61	4.92	4.71	4.58	4.54	4.58	4.71
$J = 6$	7.58	3.30	3.17	3.09	3.06	3.08	3.16
$J = 8$	4.97	2.44	2.35	2.30	2.28	2.29	2.34
$J = 10$	3.96	2.47	2.39	2.35	2.32	2.33	2.36
(b) Number of firms — Segmented markets							
$J = 3$	20.43	7.75	7.44	7.25	7.18	7.24	7.42
$J = 4$	13.61	6.09	5.86	5.73	5.67	5.70	5.81
$J = 6$	7.58	4.18	4.05	3.96	3.92	3.93	3.98
$J = 8$	4.97	3.12	3.04	2.98	2.95	2.95	2.98
$J = 10$	3.96	3.12	3.06	3.01	2.98	2.97	2.98

Notes: This table shows the number of firms for the robustness exercise with $L = 4000$ after trade costs have declined by $|\Delta\tau_{ij}| = 10\%$. Panel (a) displays the values for integrated markets. Panel (b) shows the results for segmented markets. The respective numbers are in hundreds.

Table 4.12: Robustness: Welfare Changes for Parameters

	$\gamma = 0.00$	$\gamma = 0.20$	$\gamma = 0.22$	$\gamma = 0.24$	$\gamma = 0.26$	$\gamma = 0.28$	$\gamma = 0.30$
	(a) Welfare gains — Location parameter a						
$a = 1$	1.86%	1.59%	1.56%	1.54%	1.54%	1.54%	1.55%
$a = 2$	2.26%	1.93%	1.89%	1.87%	1.86%	1.87%	1.88%
$a = 3$	2.46%	2.12%	2.08%	2.06%	2.06%	2.06%	2.07%
	(b) Welfare gains — Location parameter b						
$b = 1$	1.99%	2.29%	2.28%	2.27%	2.27%	2.26%	2.26%
$b = 2$	1.86%	1.59%	1.56%	1.54%	1.54%	1.54%	1.55%
$b = 3$	1.57%	1.05%	1.02%	1.00%	0.99%	1.00%	1.01%
	(c) Welfare gains — Shape parameter α						
$\alpha = 1$	1.86%	1.59%	1.56%	1.54%	1.54%	1.54%	1.55%
$\alpha = 2$	0.74%	1.03%	1.03%	1.03%	1.03%	1.01%	0.96%
$\alpha = 3$	0.39%	0.85%	0.77%	0.66%	0.65%	0.70%	0.75%
	(d) Welfare gains — Shape parameter β						
$\beta = 2$	1.86%	1.59%	1.56%	1.54%	1.54%	1.54%	1.55%
$\beta = 2.5$	1.33%	1.94%	1.93%	1.93%	1.92%	1.92%	1.91%

Notes: Panel (a) and Panel (b) show the welfare changes for different location parameters a and b, respectively. Panel (c) and Panel (d) show the welfare changes for different shape parameters α and β, respectively. In each panel, we deviate from the main specification only in the respective dimension.

5 Conclusion

In this thesis, I have analyzed how regional, disaggregated technology shocks diffuse through the economy and how interdependent market entry affects both heterogeneous firms in their optimal behavior and the aggregate economy in terms of welfare. Therefore, I have used extended versions of proven general equilibrium models which allow for counterfactual analysis in combination with disaggregated data to empirically validate which locations in Germany constitute the set of key regions and unveil the most important influencing factors.

In the second chapter, we have shown the importance of spatial linkages and related spillovers when discussing the aggregate effects of local productivity shocks. we have identified the set of key regions, which can be summarized as follows. Key regions should be (a) central in the production network with tight input-output linkages and trade linkages but also have (b) a low initial degree of congestion in terms of labor. If locations are too congested, rising productivity and the induced reallocation of labor leads to a more than proportional rise in input costs and a substantial increase in rents from land and structures. A second analysis has revealed that measured TFP, real GDP, and welfare could have increased by a factor of two in the period between 2010 and 2015, had key regions developed according to the observed numbers of the top performers in the German economy. we conclude that the German economy has developed below its optimum. Future research may account for the costs of making regions more productive to infer which regions should obtain subsidies, i.e., rather the economic centers or remote areas allowing the latter to catch up.

The third chapter has analyzed how market integration affects heterogeneous firms and welfare in the aggregate economy. I have used a multi-country model in which firms follow a single-pricing scheme for different markets. The results have shown that compared to segmented markets, firms charge lower prices, are less likely to export, and earn lower aggregate profits. Besides, the restriction to set one price for all markets leads to an initially lower welfare level and higher welfare gains from trade liberalization. The welfare effect strongly depends on the increasing competition for the fixed supply of labor and relates, in particular, to the rise in the labor demand by low-productivity firms. As such, declining trade cost levels lead to an increase in real wages and hence, welfare.

In the fourth chapter, I have studied in a heterogeneous firms model with innovation, how interdependent market entry affects firm-specific choices and the welfare gains from trade liberalization. Specifically, I have assumed a firm-specific technology investment choice that defines each firm's productivity for all its destination markets. Market interdependence means that the pricing and export choices depend — via the optimal investment level — on income, wages and, the export choice with respect to all markets. I have first analyzed how firms are affected by different returns to investment, thus, finding that firms set lower price levels, are more likely to export and earn larger profits. Further, there is a shift of resources to more productive firms, which increases inequality. Besides, I have shown that an increasing number of markets negatively influences firms, given the lower market size and the increasing competition for labor. In a final exercise, I have quantified the welfare gains from trade liberalization, showing that the welfare gains negatively correlate with the returns to investment but positive with the number of markets. Future research may apply this general approach to model market interdependence to different research settings, e.g., when credit constraints in the firm context create the market interdependence.

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