# Trade, Labor Markets and the Organization of Production within Firms

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Für meine Eltern

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# Abstract

The main research question of this thesis is how globalization shapes the organization of production within firms, with a particular focus on the role of labor market imperfections in open economies. For that reason, I make use of three different models to investigate the interaction between firm organization and labor market imperfections in the process of globalization. Thereby, the organization of production is discussed from different perspectives: (i) the number of products a firm is willing to produce and (ii) the organization of labor within firms. In each chapter, I use a different approach to account for imperfections in factor markets. This allows a broad discussion on how labor market institutions affect the equilibrium outcome in closed and open economies, and how these imperfections affect a firm's organization choice.

After a short introduction in Chapter 1, Chapter 2 sets up a general oligopolistic equilibrium model with multi-product firms and union wage setting. In this model, two policy experiments are conducted. First, it is shown that deunionization induces a general decline in firm scale and scope, with the respective reduction being more pronounced in non-unionized industries. Second, the consequences of trade liberalization are studied, and it is shown that access to foreign markets lowers firm scope in all industries as well as the scope differential between unionized and non-unionized firms. Adjustments in firm scale turn out to be less clearcut and *inter alia* depend on the degree of product differentiation.

Chapter 3 looks inside the firm and investigates how trade alters the matching of worker-specific abilities and task-specific skill requirements. The outcome of this matching process depends on how firms organize their recruitment process and how much they invest into the screening of applicants. In the open economy, the most productive firms start exporting. They increase their market share and therefore find it attractive to increase their screening investment, which improves the matching outcome. Things are different for non-exporters, whose market share shrinks in the open economy, lowering their incentive to invest for screening applicants. Due to this asymmetric response, access to trade raises the dispersion of productivity between heterogeneous producers, while at the same time increasing the average quality of worker-task matches and thus economy-wide labor productivity.

Chapter 4 sets up a heterogeneous firms model, where production consists of a continuum of tasks and firms hire low-skilled and high-skilled workers for

the performance of tasks, which differ in their complexity. How firms assign workers to tasks depends on factor prices for the two skill types and the productivity advantage of high-skilled workers in the performance of complex tasks. After characterizing the closed economy equilibrium with fully flexible wages, I show how firms adjust the assignment of workers top tasks in response to the introduction of a binding real minimum wage for low-skilled workers and migration of low-skilled or high-skilled workers. With a minimum wage, the opening up for trade reduces the range of tasks performed by high-skilled workers. It furthermore leads to a higher per-capita income of both skill types, which implies a higher welfare in the open than in the closed economy, while inequality between the two skill types increases. In an extension, I discuss how the firm-internal assignment of skills to tasks is affected by labor market linkages in open economies.

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# Chapter 1

# Introduction

A large number of empirical studies have documented that the largest firms in local and international markets are complex organizations, which produce multiple products in multiple sectors and many different countries.[1] For these firms, the organization of production becomes essential in surviving in a competitive globalized market. While trade economists treated firms as a "black box" for a large time, recent contributions to the literature have changed this view by looking inside the firm. This allows to discuss questions related to the organization of modern production processes from different perspectives. According to Marin (2012), the literature can be separated into two different subdisciplines. The first one addresses the boundaries of multinational firms,[2] whereas the second one focuses on the internal organization of international firms.[3] The three articles in this thesis contribute to the second subdiscipline by shedding new light on the firm internal organization, and how the organization is adjusted in response to a country's opening up for trade. Hereby, all articles in the thesis put particular emphasis on the interaction of firm organization and labor market imperfections in the context of globalization. In the remainder of the introductory section, I briefly summarize the content of Chapter 2–4, whereas a detailed discussion on how the different modeling approaches contribute to the literature is delegated to the respective chapter.

Chapter 2 analyzes how labor market imperfection affects scale and scope of multi-product firms (MPFs). To address this issue, a general oligopolistic equilibrium (GOLE) model with MPFs along the lines of Eckel and Neary (2010) is set up and enriched by assuming union wage setting in a subset of industries.[4] The asymmetry of sectors with respect to their labor market institutions is a key aspect of the analysis. It allows me to study the consequences of union wage setting on firm scale and scope in unionized industries and it provides novel insights on how labor market imperfections in certain industries spill over on firm organization in the rest of the economy. Within this framework, two comparative-static experiments are conducted. In

[1] See, for instance, Bernard, Jensen, Redding, and Schott (2007); Bernard, Redding, and Schott (2010); Yeaple (2013).

[2] See, for instance, Grossman and Helpman (2002); Antrás (2003); Antrás and Helpman (2004) and the literature cited in Marin (2012).

[3] See, for instance, Marin and Verdier (2008a, 2012); Caliendo and Rossi-Hansberg (2012) and the literature cited in Marin (2012).

[4] This chapter is based on Egger and Koch (2012), which has been published in the Canadian Journal of Economics. When working on this chapter, I have benefited from comments by Carsten Eckel and participants at the 12th Göttingen Workshop on International Economics, the European Trade Study Group, the 4th FIW Research Conference on International Economics, the Spring Meeting of Young Economists in Groningen and the 9th and 10th BGPE Research Workshop as well as seminar participants at the University of Bayreuth.

the comparative-static experiments, the focus is on two specific research questions that have sparked considerable interest in academic circles and, at the same time, are relevant for policy makers who aim at introducing measures of deregulation in product and/or labor markets. The first question is how firms absorb changes in labor market institutions, and how institutional changes in certain industries spill over on the rest of the economy. From an empirical point of view, the probably most notable change in labor market institutions is the significant decline in union relevance. This deunionization process induces an increase in the competitive as well as the union wage. In a setting with MPFs the associated cost increase renders production of those varieties that have the largest distance to a firm's core competence unattractive, so that firms reduce the scope of their product range and thus shrink at the extensive margin. Both the cost increase and the shortening of the product range induce a decline in total firm scale. Furthermore, by focusing on the production of high-competence, i.e. low-cost, varieties, all firms (except for the newly deunionized ones) can produce a higher level of output with a given level of labor input and thus are more productive on average. Finally, it is shown that deunionization by lowering the union wage premium makes firms more similar in both size dimensions, scale and scope. In a second part of this chapter, I investigate how firm scale and scope are affected if a country opens up for free trade with a symmetric partner country. Access to international trade stimulates labor demand and raises the competitive as well as the union wage, thereby lowering firm scope in all industries. Since the labor market distortion becomes less severe, unionized and non-unionized firms become more similar in the size of their product range. While scope effects are unambiguous, adjustments in firm scale turn out to be less clearcut and inter alia depend on the degree of product differentiation.

Studying the role of firms for matching workers with tasks and discussing how access to trade affects the matching outcome is the main purpose of Chapter 3.[5] Starting point of the analysis is a Melitz (2003) model, in which firms are heterogeneous due to differences in their productivity levels. As in Acemoglu and Autor (2011), it is assumed that production consists of a continuum of tasks that differ in their skill requirements. For performing these tasks, firms hire heterogeneous workers. Heterogeneity is horizontal in the sense that workers differ in their ability to perform specific tasks because their human capital is occupation-specific, while they are equally productive over the whole range of activities. This implies that all workers have the same value to firms and, lacking information about abilities of individual workers, firms randomly draw their employees from the labor supply pool. This lack of information generates a source of mismatch between task-specific skill requirements and worker-specific abilities within the boundaries of a production unit. To reduce this mismatch, firms can invest into a screening technology for gathering some (imperfect) information about the abilities of their workforce. A higher investment provides better knowledge about the abilities of workers and therefore leads to a better match of these workers with the different tasks in the production process. The incentives to screen are more pronounced in larger firms, and hence there is an additional source of heterogeneity in this model, which is endogenous and reinforces heterogeneity of firms due to exogenous differences in firm productivity. This model is used to shed new light on the consequences of trade for labor market outcome, thereby focussing on adjustments in the firm-internal labor market. To be more specific, it is analyzed how trade affects underemployment arising from a mismatch be-

[5]This chapter is based on Egger, Koch (2013). When working on this chapter, I have benefited from comments by Carsten Eckel, James Harrigan, Frode Meland, Marc Muendler, Frank Stähler and participants at the European Trade Study Group Meeting in Leuven, the GEP Postgraduate Conference in Nottingham, the Göttingen Workshop on International Economics, the Midwest International Economics Meeting at the Indiana University, the Brown Bag Seminar of the Department of Economics at the University Bayreuth, the Research Workshop of the Bavarian Graduate Program in Economics (BGPE) and the Economics Research Seminars at the University of Bergen and the University of Tuebingen.

tween worker-specific abilities and task-specific skill requirements. To keep the analysis simple, the focus is on trade between symmetric countries while considering the empirically relevant case, in which only the most productive firms export in the open economy. Having access to the export market, high-productivity firms can expand their market share in the open economy, which provides an incentive for these firms to screen their workforce more intensively, as this further improves the matching quality and thus lowers production costs. Low-productivity non-exporters, on the other hand, lose market share and thus lower their investment into the screening technology, which raises their production costs. By changing the cost structure, this asymmetric response to trade liberalization exerts a feedback effect on the entry/exit decision of firms in both the domestic and the export market, which is not present in other trade models with heterogeneous firms. Furthermore, it alters the productivity distribution of active firms by driving a wedge between matching efficiency of exporters and non-exporters. Finally, adjustments in the firm-internal labor allocation process lower the *aggregate* mismatch between worker-specific abilities and task-specific skill requirements, thereby generating a productivity stimulus that reinforces the gains from trade in an otherwise identical Melitz (2003) model.

Chapter 4 builds upon the framework studied in Chapter 3 and sets up a heterogeneous firms model in which a firm's output is manufactured using a continuum of tasks.[6] Firms hire low-skilled and high-skilled workers for the performance of tasks. Tasks differ in their complexity and workers differ in their ability to perform these tasks, with high-skilled workers having a comparative advantage in performing more complex tasks. How firms organize the firm-internal production process by assigning skills to tasks depends on the respective factor costs and productivity advantage of high-skilled workers in performing more complex tasks. This framework is used to analyze how imperfections in the labor market affect the firm-internal assignment of skills to tasks in the closed economy. After characterizing the autarky equilibrium outcome with fully flexible wages for both skill types, a (real) minimum wage is introduced, that is set by the government for low-skilled workers and causes involuntary unemployment of that skill type. As relative factor prices are changed and low-skilled task production becomes more costly, firms assign high-skilled workers to a broader range of tasks. This firm-internal skill upgrading improves a firm's labor productivity. However, as more high-skilled workers are employed for the performance of tasks, less of them are left to manage firms and the mass of firms therefore declines. Firm exit triggers a decline in aggregate output, income and welfare. After discussing migration of low-skilled and high-skilled workers under the two different labor market regimes, the model is used to discuss how trade between two countries affects the firm-internal production process. Only when low-skilled wages are set by a binding minimum wage, trade exerts an impact on the firm-internal assignment process. The opening up to trade raises demand for each firm due to a standard division of labor effect. When the factor price for low-skilled workers is fixed, the skill premium increases implying that high-skilled task production becomes relatively unattractive. Firms respond in broadening the range of tasks produced with low-skilled workers, which reduces labor productivity of each firm. Beside this negative productivity effect, trade increases the mass of producers in each country and reduces the unemployment rate of low-skilled workers. This causes an increase in the relative income of both workers with the respective increase being more pronounced for high-skilled workers. Furthermore, aggregate output, income and welfare goes up. Moreover, high-skilled workers gain in relative terms as their skill premium and relative per-capita income increases. After discussing the movement from autarky to trade, it is shown how changes in local endowments and labor market institutions

[6]When working on this chapter, I have benefited from comments by Carsten Eckel, Hartmut Egger and participants at the European Trade Study Group Meeting in Birmingham, the IO and Trade Seminar at the Department of Economics at the University of Munich and the Brown Bag seminar at the University of Bayreuth.

spill over to the partner country. Thereby, it is shown that an increase in the minimum wage abroad reduces the range of tasks performed by low-skilled workers at home, while it increases the productivity of active producers there. Both skill types end up with a lower per-capita income, and thus welfare is reduced at home.

Finally, Chapter 5 concludes with a brief summary of the most important results.

# Chapter 2

# Labor Unions and Multi-Product Firms in Closed and Open Economies

## 2.1 Introduction

In this chapter, we analyze how labor market imperfection affects scale and scope of multi-product firms (MPFs). To address this issue, we set up a general oligopolistic equilibrium (GOLE) model with MPFs along the lines of Eckel and Neary (2010) and enrich this framework by assuming union wage setting in a subset of industries. The asymmetry of sectors with respect to their labor market institutions is a key aspect of our analysis. It allows us to study the consequences of union wage setting on firm scale and scope in unionized industries and it provides novel insights on how labor market imperfections in certain industries spill over on firm organization in the rest of the economy. Within this framework, we undertake two comparative-static experiments. First, we investigate the consequences of deunionization on firm scale and scope in industries that are directly exposed to this institutional change as well as in industries whose labor market institutions do not change. Second, we study the differential impact of trade liberalization on firm scale and scope in unionized and non-unionized industries.

Relying on the Eckel and Neary (2010) framework, we assume a continuum of industries and a small (exogenous) number of firms competing in quantities within each of these industries. Firms employ labor to produce a range of differentiated product varieties. They have a core competence in one of these varieties which they produce at the lowest marginal cost. By expanding the scope of their product range, firms start manufacturing varieties with a larger distance to their core competence and thus higher marginal production costs.[1] Setting a markup on the competitive

[1]Abstracting from any additional costs of introducing a new variety the model captures the idea of flexible manufacturing, which is a widely used concept of representing MPFs (see Milgrom and Roberts, 1990; Eaton and Schmitt, 1994; Norman and Thisse, 1999; Eckel, 2009). While there are many alternative ways of modeling MPFs (see, for instance, Feenstra and Ma, 2008; Nocke and Yeaple, 2008; Arkolakis and Muendler, 2010; Mayer, Melitz, and Ottaviano, 2010; Bernard, Redding, and Schott, 2011), there are good reasons for relying on the Eckel and Neary (2010) approach when accounting for union wage setting. With oligopolistic competition between a small number of competitors and linear demand in each industry, our model is related to a large and well-established literature on unionized oligopoly. Thus, we can directly compare our results with findings from this literature to highlight whether and how previous insights on the interplay between labor market and product market imperfections have to be modified if one accounts for multi- instead of single-product firms.

wage, labor unions enforce a reduction in the output and employment level of unionized firms. While this effect does also exist in other models of unionized oligopoly, there is an additional adjustment margin in a setting with MPFs. By raising marginal production costs, unions reduce the incentive of firms to operate a wide product range and thus lower firm scope. Furthermore, union wage setting lowers aggregate employment *ceteris paribus* and thus induces a fall in the market-clearing competitive wage. The decline of the competitive wage raises firm scale and scope in non-unionized industries. This points to a new facet of spillovers associated with union wage setting. Unions do not only influence wage payments in other sectors (due to labor market clearing) but also affect the product range of non-unionized producers – and thus labor productivity in our setting.

In the comparative-static experiments, we focus on two specific research questions that have sparked considerable interest in academic circles and, at the same time, are relevant for policy makers who aim at introducing measures of deregulation in product and/or labor markets. The first question we are interested in is how firms absorb changes in labor market institutions, and how institutional changes in certain industries spill over on the rest of the economy. From an empirical point of view, the probably most notable change in labor market institutions is the significant decline in union relevance. This *deunionization* process is a worldwide phenomenon which has been observed in all industrialized economies over the last four decades (see OECD, 2004). From Bastos and Kreickemeier (2009) we know that in an otherwise similar framework with single product firms (SPFs), deunionization – captured by a decline in the share of unionized industries – raises the competitive as well as the union wage and thus lowers scale of both unionized and non-unionized firms. Since the union wage increases less than proportionally, deunionization lowers the scale differential between the two types of producers.

In this chapter, we show that firm-level adjustments become more sophisticated when firms produce more than just a single variety and that the endogeneity of the product range leads to further interesting results upon how firms respond to changes in labor market institutions. To be more specific, deunionization induces an increase in the competitive as well as the union wage, similar to the model with SPFs. However, in a setting with MPFs the associated cost increase renders production of those varieties that have the largest distance to a firm's core competence unattractive, so that firms reduce the scope of their product range and thus shrink at the extensive margin. Both the cost increase and the shortening of the product range induce a decline in total firm scale. Furthermore, by focusing on the production of high-competence, i.e. low-cost, varieties, all firms (except for the newly deunionized ones) can produce a higher level of output with a given level of labor input and thus are more productive on average. Finally, we show that deunionization by lowering the union wage premium makes firms more similar in both size dimensions, scale and scope, in our setting.

In a second application of our model, we investigate how firm scale and scope are affected if a country opens up for free trade with a symmetric partner country. As pointed out by Brander (1981), a movement from autarky to trade raises competition in an oligopolistic market and thus provides a stimulus for the production of all firms *ceteris paribus*. In a general equilibrium environment with factor market clearing, this induces an increase in the competitive wage, which counteracts the partial equilibrium production stimulus. As outlined by Neary (2009), in a model with SPFs, symmetric industries, and no labor market distortions, the two effects cancel and thus firm scale remains unaffected by the trade shock. In an otherwise identical model with MPFs, firms lower their scope in response to a higher competitive wage, thereby leaving more labor for employment in activities that are closer to the firms' core competences. To put it in the words of Eckel and Neary (2010) firms are *leaner and meaner* in the open economy and they experience a productivity surge as their total output increases for a given level of labor input. This points to a new channel through which gains from trade can materialize, one that is specific to models of MPFs.

By extending the Eckel and Neary (2010) framework to one with labor market imperfections, we further enrich the picture of possible firm-level adjustments to globalization. As in textbook models of unionized oligopoly with SPFs, trade exerts a union-disciplining effect and thus lowers union wage claims *ceteris paribus* (Huizinga, 1993; Sørensen, 1993). Hence, both scale and scope effects of trade are more pronounced in unionized industries, so that economic activity shifts towards these sectors. All other things equal, this lowers production in non-unionized industries and the shift effect may actually be strong enough to dominate the output stimulus from being more focused on the production of high-competence varieties. Hence, labor market imperfections render firm-level adjustments to international trade more sophisticated and less clearcut than one might have expected from the analysis in Eckel and Neary (2010).

Aside from looking at pure level effects, we are particularly interested in the differential impact that trade exerts on unionized and non-unionized firms. In this respect, we show that trade weakens the labor market distortion and thus lowers the union wage premium. This effect is instrumental for a reduction in the scope differential between the two types of producers. Similarly, the decline in the union wage premium also reduces the domestic output differential of local producers. However, this effect is counteracted by a widening of the output gap at the extensive margin as, after a country's opening up for trade, firms start exporting and the respective exports are larger for non-unionized than for unionized firms. Which of these two effects dominates is not clearcut in general and depends on the degree of product differentiation. Smaller degrees of product differentiation reinforce the pro-competitive effect of trade and thus amplify the union-disciplining effect of foreign competition. This strengthens the negative impact of trade on the domestic production gap between unionized and non-unionized producers, so that the scale differential decreases for small degrees of product differentiation. On the contrary, for high degrees of product differentiation it is the output expansion effect in the export market that dominates so that the firm scale differential increases in response to trade.

The remainder of the chapter is organized as follows. In Chapter 2.2 we introduce the main assumptions, describe the basic model structure, and characterize the autarky equilibrium. After a brief discussion on how union wage setting affects firm scale and scope, we study how MPFs respond to deunionization. In Chapter 2.3, we characterize the equilibrium in an open economy with free trade between two symmetric countries and compare the outcome in the open economy with the one in the closed economy to shed light on how trade affects union wage setting as well as firm scale and scope in the presence of labor market imperfection. Chapter 2.4 concludes with a brief summary of the most important results.

## 2.2 MPFs and imperfect labor markets: The closed economy

The country under consideration hosts a continuum of industries, with an oligopolistic market structure and a small (exogenous) number $n$ of firms in each of these industries. The industries are identical in all respects except for the prevailing labor market institutions. While firms in a subset of industries are exposed to union wage-setting, firms in the rest of the economy pay the competitive wage, which is determined by a standard labor market clearing condition – provided that labor is homogeneous and fully mobile across sectors. With respect to union wage-setting, we apply a monopoly union framework, in which unions unilaterally set wages prior to the firms' choice of employment, which in our setting involves the simultaneous decision upon firm scale and scope.

### 2.2.1 Preferences and consumer demand

There exists a representative consumer, whose preferences are represented by a two-tier quasi-homothetic utility function. The upper tier is an additive function of a continuum of sub-utilities, each of them corresponding to one industry $z \in [0,1]$:

$$U[u\{z\}] = \int_0^1 u\{z\}\, dz. \tag{2.1}$$

Each sub-utility is a quadratic function of consumption levels $q(i,z)$, $i \in [1, N(z)]$, where $N(z)$ is the measure (or, in the interest of a more accessible interpretation, the *number*, henceforth) of differentiated varieties produced in industry $z$. To be more specific, we assume

$$u\{z\} = a\int_0^{N(z)} q(i,z)di - \frac{1}{2}b\left[(1-\rho)\int_0^{N(z)} q(i,z)^2 di + \rho\left(\int_0^{N(z)} q(i,z)di\right)^2\right], \tag{2.2}$$

where $a$, $b$ denote non-negative preference parameters with the usual interpretation and $\rho$ is an inverse measure of product differentiation, which is assumed to lie between 0 and 1.[2]

Aggregate demand in this setting is determined by maximizing utility of the representative consumer subject to her budget constraint

$$\int_0^1 \int_0^{N(z)} p(i,z)q(i,z)didz \leq I, \tag{2.3}$$

where $p(i,z)$ denotes prices for variety $i$ in industry $z$ and $I$ is aggregate income of the economy. This gives

$$p(i,z) = \frac{1}{\lambda}\left(a - b[(1-\rho)q(i,z) + \rho\int_0^{N(z)} q(i,z)di]\right), \tag{2.4}$$

where $\lambda$ is the representative consumer's marginal utility of income. As it has become standard in the literature, we choose utility as the numéraire and set $\lambda$ equal to one. Thus, all nominal variables are measured relative to the representative consumer's marginal utility of income (see Neary, 2009, for further discussion).

From Eq. (2.4) we can infer insights upon the role of preference parameter $\rho$ in our setting. As mentioned above, $\rho$ is a measure of product differentiation and lies in interval $[0,1]$. If $\rho = 1$ products are homogeneous (perfect substitutes), so that the price is linear in total industry consumption: $p(i,z) = a - b\int_0^{N(z)} q(i,z)di$. In the other limiting case with $\rho = 0$, goods are perfectly differentiated in the perception of consumers, so that the price for each variety only depends on consumption of this variety but is independent of the consumption of all other varieties in this industry. In the latter case, indirect demand is given by $p(i,z) = a - bq(i,z)$.

[2] By formulating the respective preferences of the representative consumer, we have presumed that the following two conditions are fulfilled for any individual consumer: participation in the market for any good $i$ and non-satiation in the consumption of these goods. Clearly, both of these conditions depend on endogenous variables. However, under the additional assumption of identical consumer preferences, we know from previous work that these conditions are fulfilled if a lump-sum tax-transfer system redistributes a sufficient level of income from rich to poor agents. Being not interested in income distribution or individual welfare levels *per se*, we can thus safely assume that the two conditions are fulfilled throughout our analysis.

### 2.2.2 Technology, production, and profit maximization

We associate MPFs with the idea of flexible manufacturing, and thus assume that firms can expand their product range "with only a minimum of adaptation" (Eckel and Neary, 2010, p.192). The costs of adaptation are modeled by higher labor requirements for producing a unit of output of a firm's non-core competence product, and the respective adaptation costs are assumed to be monotonically increasing in the distance between a specific product to the firm's core competence variety. However, adding a new variety to the product range does not alter the costs of producing other varieties nor does it involve any fixed costs. To put it formally, we denote marginal production costs of firm $j = 1, ..., n$ in industry $z$ for producing variety $i$ by $c_j(i,z) = \gamma_j(i)w_j(z)$, with $\gamma_j(i)$ being the constant labor input coefficient for producing variety $i$ and $w_j(z)$ being the wage rate in industry $z$. We associate firm $j$'s core competence with variety $i = 0$ and capture flexible manufacturing by assuming $\partial c_j(i,z)/\partial i = \partial\gamma_j(i)/\partial i \times w_j(z) > 0$. While the main mechanisms of our analysis do not hinge on a specific functional form of $\gamma_j(i)$, we impose the additional assumption $\gamma_j(i) = e^i$ in the interest of analytical tractability. Furthermore, we assume that product ranges are firm-specific, implying that each firm has its own core competence and produces its own set of varieties.[3] Finally, as pointed out above, we allow for sectoral differences in labor market institutions and thus end up with industry-specific wage rates. Hence, in contrast to Eckel and Neary (2010) marginal production costs in our model comprise both a product-specific component, $\gamma_j(i)$, and a sector-specific one, $w_j(z)$.

Considering the technology assumptions above and denoting by $\delta_j(z)$ the scope of the product range, profits of firm $j$ in industry $z$ are given by

$$\Pi_j(z) = \int_0^{\delta_j(z)} \big[p_j(i,z) - c_j(i,z)\big] x_j(i,z) di, \tag{2.5}$$

where $x_j(i,z)$ denotes output of variety $i$. Firms simultaneously choose the output level of all of their products as well as the scope of the product range. Wages (and thus marginal production costs $c_j(i,z)$) are exogenous from the perspective of individual producers. While the competitive wage is an economy-wide variable and thus not affected by a single firm's decision upon its scale and scope, the unionized wage is determined before the firm sets $x_j(i,z)$ and $\delta_j(z)$ and thus also treated as exogenous in the output game. Taking account of the market clearing condition $x_j(i,z) = q_j(i,z)$ and maximizing $j$'s profits in (2.5) with respect to $x_j(i,z)$ gives the first-order condition

$$\frac{\partial\Pi_j(z)}{\partial x_j(i,z)} = p_j(i,z) - c_j(i,z) - b\left[(1-\rho)x_j(i,z) + \rho X_j(z)\right] = 0,$$

with $X_j(z) \equiv \int_0^{\delta_j(z)} x_j(i,z)di$ denoting firm scale. Substituting (2.4) and denoting industry-wide output of all $n$ producers by $Y(z) = \int_0^{N(z)} x(i,z)di$ we can solve for

$$x_j(i,z) = \frac{a - c_j(i,z) - b\rho(X_j(z) + Y(z))}{2b(1-\rho)}. \tag{2.6}$$

The negative impact of industry output $Y(z)$ on firm $j$'s profit-maximizing output of variety $i$ captures the fact that under Cournot competition (and linear demand) output levels are

[3] Adaptation costs do not depend on the degree of product differentiation in consumer demand. This renders the analysis simple and allows us to study preference and technology changes as two independent phenomena. However, the respective results from our analysis may be restrictive if adaptation costs vary systematically with the degree of product differentiation, which could be the case in industries in which products are tailored to specific needs of individual consumers.

strategic substitutes. Furthermore, the additional negative impact of this firm's own total output $X_j(z)$ reflects the cannibalization effect, i.e. under Cournot competition MPFs internalize that increasing output of a certain variety lowers prices for this as well as all other varieties in the firm's product range. Both of these effects do exist if and only if $\rho > 0$, i.e. if products are not perfectly differentiated (see above).

Furthermore, maximizing profits (2.5) with respect to $\delta_j(z)$ gives the first-order condition

$$\frac{\partial \Pi_j(z)}{\partial \delta_j(z)} = [p_j(\delta_j(z)) - c_j(\delta_j(z))]\, x_j(\delta_j(z)) = 0,$$

which can be solved for firm $j$'s optimal product range

$$\delta_j(z) = \ln\left[\frac{a - b\rho(X_j(z) + Y(z))}{w_j(z)}\right]. \tag{2.7}$$

Comparing Eqs. (2.6) and (2.7), we see that firms add new varieties to their product portfolio until the marginal costs of the last variety $\delta_j(z)$ equals the marginal revenue of this variety at zero output. Using the latter insight in Eq. (2.6), we can derive a second expression for optimal output of variety $i$, by expressing the respective output level of this variety in terms of the difference between its own marginal cost and that of the marginal variety:

$$x_j(i,z) = \frac{w_j(z)[e^{\delta_j(z)} - e^i]}{2b(1-\rho)}. \tag{2.6$'$}$$

Integrating output $x_j(i,z)$ over all varieties $i$, finally gives total output, i.e. the scale, of firm $j$:

$$X_j(z) = \frac{w_j(z)}{2b(1-\rho)}\left[e^{\delta_j(z)}\left(\delta_j(z) - 1\right) + 1\right], \tag{2.8}$$

which, all other things equal, increases in the firm's product range $\delta_j(z)$ and, for a given scope, increases in wage rate $w_j(z)$. The latter effect has to be interpreted with care, as it does not imply that higher factor costs increase firm size. Rather, higher wages lead to output adjustments at the internal and the external margin. The former is associated with a firm's relocation of production from goods with a large distance towards goods with a small distance to its core competence, holding the product range and output of the marginal variety constant. The latter is associated with a change in the product range. The positive impact of an increase in $w_j(z)$ on $X_j(z)$ for a given $\delta_j(z)$ only captures the firm's output adjustment at the intensive margin and accordingly should be interpreted as a partial effect. As outlined below, this adjustment at the internal margin is counteracted and dominated by a firm's output adjustment at the external margin, so that total firm size decreases in response to higher labor costs, as can be expected.

### 2.2.3 Union wage setting and the labor market

Regarding factor endowments, we assume that the country under consideration is populated by $L$ workers, each of them supplying one unit of labor. Workers are mobile across sectors, with sectors differing in the prevailing labor market institutions. To be more specific, we apply the labor market model of Bastos and Kreickemeier (2009) and assume that a subset of industries is unionized, while in the rest of the economy, the labor market is perfectly competitive. Without loss of generality, we order industries such that unions are active in all sectors with $z \leq \tilde{z}$. Provided that unions are only active in a subset of industries, i.e. $\tilde{z} < 1$, involuntary unemployment does not materialize in this setting, as workers who do not find a job in unionized industries will move to non-unionized industries, and the competitive wage will fall until all workers can find employment there. With respect to wage setting in industries $z \in [0, \tilde{z}]$, we consider sector-level unions which unilaterally set wages that are binding for all workers of the respective industry, while, at the same time, leaving the right-to-manage employment to firms. Since all firms of an industry pay identical wages they are symmetric, and hence we can combine (2.8) and (2.7) to obtain[4]

$$e^{\delta(z)} = \frac{a/w(z) - \phi}{1 + \phi\delta(z) - \phi}, \tag{2.9}$$

where $\phi \equiv \rho(n+1)/[2(1-\rho)]$ is a measure of product market competition, which positively depends on the number of competitors, $n$, and negatively depends on the degree of product differentiation, as captured by the inverse of $\rho$. Eq. (2.9) establishes a negative relationship between wage rate $w(z)$ and firm scope $\delta(z)$. Furthermore, Eqs. (2.8) and (2.9) determine firm scale $X(z)$ as an implicit function of $w(z)$, and it is shown in the Appendix that $dX(z)/dw(z) < 0$, as argued above.

The response of firm scale and scope to changes in the wage rate is taken into account by unions. As in other models of union wage setting, unions face a trade-off between higher wages and higher employment when deciding upon their wage claims. How unions evaluate this trade-off depends on their objective function. We impose the common assumption that unions are utilitarian and have an objective function of the form $\Omega(z) = [w(z) - w^c]nl(z)$, where $w^c$ is the economy-wide competitive wage. Substituting $l(z) = \int_0^{\delta(z)} e^i x(i,z)di$, $x(i,z)$ from (2.6′), and $e^{\delta(z)}$ from (2.9) into union objective $\Omega$, we obtain[5]

$$\Omega = \frac{n}{4b(1-\rho)} (w^u - w^c) w^u \left( \frac{a/w^u - \phi}{1 + \phi\delta^u - \phi} - 1 \right)^2. \tag{2.10}$$

Totally differentiating the latter with respect to $w^u$ and setting the resulting expression equal to zero gives the first-order condition

$$\frac{d\Omega}{dw^u} = \frac{n}{4b(1-\rho)} \left( \frac{a/w^u - \phi}{1 + \phi\delta^u - \phi} - 1 \right) \left[ (2w^u - w^c) \left( \frac{a/w^u - \phi}{1 + \phi\delta^u - \phi} - 1 \right) \right.$$
$$\left. -2(w^u - w^c) \frac{e^{\delta^u}(1 + \phi\delta^u - \phi) + \phi}{1 + \phi\delta^u} \right] = 0.$$

Rearranging terms and accounting for (2.9) allows us to derive the union wage claim as an implicit function of the competitive wage $w^c$:

$$w^u = \frac{1}{2} w^c + \frac{a}{[1 + \phi\delta^u][e^{\delta^u} - 1]} \left[ 1 - \frac{w^c}{w^u} \right]. \tag{2.11}$$

Unions set wages $w^u > w^c$ and thus end up with lower scale and scope. Furthermore, our model reproduces the common result that a higher competitive wage (and thus a higher alternative income) provides a stimulus for the union wage, i.e. $dw^u/dw^c > 0$.[6]

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[4]We suppress firm indices from now on to simplify notation.

[5]Since sectors only differ in their labor market institutions, we introduce superscripts $u$ and $c$ to refer to unionized and non-unionized industries, respectively, and suppress sector index $z$ from now on.

[6]The proof of this result is deferred to the Appendix.

The competitive wage is not exogenous in our model but adjusts in general equilibrium to clear the labor market. Substituting $x(i,z)$ from Eq. (2.6′) into $L = \int_0^1 \int_0^{\delta(z)} ne^i x(i,z) di dz$, we can write the condition for labor market clearing as follows:

$$L = \frac{n}{4b(1-\rho)} \left[ \tilde{z} w^u \left( e^{\delta^u} - 1 \right)^2 + (1-\tilde{z}) w^c \left( e^{\delta^c} - 1 \right)^2 \right], \tag{2.12}$$

where the left-hand side of this equation represents exogenous labor supply, while the right-hand side represents aggregate labor demand. Together with Eqs. (2.8), (2.9) – separately for unionized and non-unionized industries – and (2.11) this gives a system of six equations, which jointly determine the autarky level of the six endogenous variables $w^c$, $w^u$, $\delta^c$, $\delta^u$, $X^c$ and $X^u$. This completes the characterization of the closed economy equilibrium.

### 2.2.4 The consequences of deunionization for firm-level variables

With the characterization of the closed economy equilibrium at hand, we are now equipped to investigate how firms respond to a fall in the share of unionized industries, $\tilde{z}$. We summarize the main insights from this comparative-static analysis in the following proposition.

**Proposition 1** *A decline in the share of unionized industries lowers firm scale and scope, while raising labor productivity in all industries, except of the newly deunionized ones.*

**Proof.** See the Appendix. ■

Since non-unionized firms employ more workers than unionized ones, a fall in $\tilde{z}$ provides an employment stimulus in the newly deunionized industries and thus raises economy-wide labor demand. Due to the requirement of labor market clearing, this induces an increase in $w^c$ and $w^u$. The higher factor costs prompt firms to use their labor input more productively, thereby inducing a shortening of the product range (see (2.9)). At the same time, firms reduce the output of each interior variety, and they do so more than proportionally for varieties that are further away from their core competence (see (2.6′)). Hence, all MPFs (except for the newly deunionized ones) end up with smaller scale and scope, and higher labor productivity.[7] By construction, such a productivity increase does not materialize in models with SPFs, provided that output of a specific variety is linear in labor input (see Bastos and Kreickemeier, 2009).[8]

Aside from studying pure level effects, we can also shed light on the differential impact a decline in $\tilde{z}$ exerts on unionized and non-unionized firms. The respective insights are summarized in the following proposition.

**Proposition 2** *Provided that the degree of product differentiation is sufficiently high, a decline in the share of unionized industries lowers the scale differential $\Delta \equiv \delta^c - \delta^u$ as well as the scope differential $\Xi \equiv X^c - X^u$ between firms in non-unionized and unionized industries.*

[7] Clearly, this productivity increase is a consequence of associating MPFs with flexible manufacturing and the assumption of higher unit production costs for goods that are further away from a firm's core competence, while, as pointed out by an anonymous referee, counteracting effects would materialize if economies of scope could be exploited by an increase in the product range – an effect that is absent in our model.

[8] Of course, by affecting firm scope, deunionization also changes the total number of available product varieties. This may be an important channel through which welfare effects of deunionization materialize. We have studied these welfare effects in detail, but due to space constraints have deferred the welfare analysis to the Appendix and only report the main insights from this analysis here: Similar to its impact on the number of available varieties, deunionization exerts a non-monotonic impact on welfare in our model, with the respective effect being positive for small initial levels of $\tilde{z}$ and negative for high initial levels of $\tilde{z}$.

**Proof.** See the Appendix. ■

While deunionization increases both $w^c$ and $w^u$, the respective factor price stimulus turns out to be stronger in competitive industries, implying that the union wage premium $\omega \equiv w^u/w^c$ falls. As formally shown in the Appendix, this decline in $\omega$ is instrumental for rendering firms more similar in both scale and scope, at least if $\rho$ is sufficiently small.

To round off the analysis of the closed economy, we briefly discuss whether our theoretical insights upon the interaction between firm scale and scope, on the one hand, and labor market institutions, on the other hand, are in accordance with empirical evidence. The main advantage of a general equilibrium framework is its suitability for studying cross-sectoral linkages through economy-wide factor market clearing. In our setting, these linkages lead to spillovers of deunionization on wages in other industries. To be more specific, deunionization of certain industries lowers the wages within these industries relative to other ones.[9] As pointed out above, this stimulates economy-wide labor demand and thus raises the labor return in all other (unionized and non-unionized) industries. This spillover effect has received considerable attention in the labor market literature and has strong empirical support.[10]

In our model, the spillover of deunionization on wage payments in other industries changes the firms' profit maximizing choice of scale and scope, there. While these additional spillover effects have to the best of our knowledge not been at the agenda of empirical research so far, shedding light on these effects may be useful for getting a more comprehensive picture upon how labor market institutions affect the economic well-being in modern societies. That firm-level adjustments to union activity are important for total output can be inferred from the observation that unionized firms have, all other things equal, lower employment and profits. While there is indeed strong empirical support for a negative impact of unions on these two measures of firm performance, existing evidence regarding the impact of unionization on labor productivity is less clear (see Turnbull, 2003). Many economists would agree that unions reduce the incentives for investment and thereby lower labor productivity. But it is difficult to find strong evidence for this theoretically convincing argument. Our model suggests that changes in firm scope counteract the negative productivity effects as firms lower their product range when facing higher wage costs (with feedback effects on other industries), and thus it offers an explanation for why conclusive evidence for a negative impact of unionization on labor productivity is missing.[11]

[9] We do not put emphasis on absolute changes in the competitive and the union wage, as they are measured in terms of the representative consumer's utility and therefore represent real wages *at the margin* (see Neary, 2009). For that reason, we cannot directly compare our findings with empirical evidence on real wage effects of deunionization. The relative loss of workers in newly deunionized industries, on the other hand, is a simple consequence of union members receiving a wage premium which is well supported by empirical evidence (see, for instance, Freeman and Medoff, 1981).

[10] The literature distinguishes two types of spillovers of union wage setting on non-union workers. On the one hand, workers move from unionized to non-unionized firms, generating additional labor supply and lowering wages there. On the other hand, firms may be willing to pay higher wages due to the threat of union formation if wage gaps between unionized and non-unionized producers are too large (Freeman and Medoff, 1981). While there is empirical support for both types of spillover effects (see Neumark and Wachter, 1995; Farber, 2005; Fitzenberger, Kohn, and Lembcke, 2008), only the first one is present in our model as the share of unionized firms/industries is assumed to be exogenous throughout our analysis.

[11] Doucouliagos and Laroche (2009) put it in the following way: "The broad view emerging from [the] literature is that the impact of unions on profitability is *a priori* indeterminate: any positive effect of unions on productivity may be offset by higher production costs, while any negative effect on productivity reinforces cost pressures" (p. 146f).

## 2.3 MPFs and labor market imperfection in an open economy

It is the purpose of this chapter to shed light on firm level adjustments if the country under consideration opens up to trade. Thereby, we consider trade between two fully symmetric economies and abstract from the existence of any impediments of shipping goods across borders. Product markets are segmented and labor is not allowed to move across borders. In the interest of readability, we do not repeat all the steps of the formal analysis in Chapter 2.2, but instead stick to an informal discussion of the trade effects on firm scale and scope in the main text of our chapter, while deferring derivation details of the analysis to the Appendix.

We start our analysis with first focusing at the benchmark scenario with $\rho = 0$. As outlined in the previous chapter, firms behave as monopolists in this case. Hence, access to trade does not change the competitive environment and all trade effects materialize due adjustments of factor costs in general equilibrium. To be more specific, firms start serving foreign consumers in the open economy and thus expand production and labor demand at the extensive margin. To restore the labor market equilibrium, the competitive wage must increase and unions respond to this increase in $w^c$ by raising their wage claims. The surge in factor costs causes a shortening of the product range of all competitors and firm scope falls in unionized as well as non-unionized industries. This is instrumental for a productivity surge. With respect to firm scale, we can note that the increase in factor costs lowers the output of firms for the domestic market. However, in the open economy firms additionally serve foreign consumers and this expansion at the extensive margin dominates the output reduction, so that firm scale unambiguously increases in all industries when a country opens up for trade. This effect is intuitive, as the decline in firm scope leaves more labor for employment in the firms' high-competence varieties which means that resources are used more productively and firm scale can expand in the open economy. This outcome is in line with the key finding of Eckel and Neary (2010) that firms become *leaner and meaner* when a country opens up for trade, thereby generating productivity gains which refer to a new channel through which gains from trade can materialize, a channel that is not present in textbook models of trade with SPFs.

In order to determine how trade affects relative firm performance, it is worth noting that union wage claims, while stimulated by the surge in the competitive wage, increase less than proportionally, so that the union wage premium, $\omega$, shrinks when the country opens up for trade with a symmetric partner country. The fall in the wage differential reduces the cost disadvantage of unionized firms, thereby lowering the differential in firm scope across industries, i.e. $\Delta$ is lower in the open than in the closed economy. The fall in the union wage premium is also instrumental for a decline of the output differential in the domestic market. However, with market-specific output being larger in non-unionized sectors, firms in these industries experience a more than proportional output increase from exporting. It is this second effect that dominates in our model, so that the firm scale differential, $\Xi$, is magnified in the open economy if $\rho = 0$.

Equipped with the insight from the closed economy that, due to differentiability of the main variables of interest, the findings from the benchmark scenario with $\rho = 0$ extend to high degrees of product differentiation (i.e., low levels of $\rho$), we can formulate the following proposition.

**Proposition 3** *Provided that the degree of product differentiation is sufficiently high, a country's movement from autarky to trade with a symmetric partner country lowers firm scope and raises firm scale as well as labor productivity in all industries. Furthermore, the scope differential shrinks, while the firm size differential increases between firms from non-unionized and unionized industries.*

**Proof.** See the Appendix. ■

The results from Proposition 3 are useful for explaining several empirical regularities. One of these regularities is that exporting has a positive impact on firm size (see, for instance, Wagner, 2002). While this effect is also present in models of heterogeneous SPFs along the lines of Melitz (2003), the mechanisms behind the respective adjustments differ significantly between the two settings. In a Melitz-type model, firm size increases due to a relocation of labor towards more productive firms. In our setting, there is also relocation of employment from non-unionized to unionized producers. However, this relocation is not decisive for the positive output effect. To be more specific, in our model with MPFs total output would increases as well, if employment stayed constant in any firm (which would be the case, for instance, if $\tilde{z} \to 0$). The reason is that export opportunities increase wages and render a shortening of the product range attractive from the perspective of each individual producer. Accounting for sector-specific labor market institutions, our model is thus suited for disentangling output effects that materialize due to relocation of labor and output effect that are attributable to a shortening of the product range. A further implication of our model is that firm productivity increases when a country opens up for trade, and this effect is again driven by a stronger focus on core-competence products in response to higher wage payments in the open economy. This provides an explanation for the empirical finding that exporting increases firm productivity (see Bernard, Jensen, and Schott, 2006; Greenaway and Kneller, 2008) – without relying on a learning mechanism for which direct empirical evidence is still missing.[12] Finally, our model also provides an rationale for the empirical finding in di Giovanni, Levchenko, and Rancière (2011) that trade raises the variance in firm size. While these authors explain their observation by means of a modified Melitz model with heterogeneous SPFs, we show that differences in the prevailing labor market institutions may also generate such an outcome in a setting with otherwise symmetric MPFs.[13]

With partial product differentiation access to international trade gives rise to pro-competitive effects, which materialize along multiple lines. On the one hand, trade fosters product market competition and thus reduces profits *ceteris paribus*. While in a model with SPFs this does not exert a direct effect on union wage setting, it induces a fall in firm scope and thus gives room for higher union wage claims in our setting. On the other hand, trade changes the labor market environment. While sector-level unions unilaterally set industry-wide wage standards in the closed economy, they have to account for the outcome of union wage setting in the foreign economy when the opening up for trade exposes domestic producers to international competition. All other things equal, this gives rise to a union-disciplining effect and induces a fall in union wage claims. Hence, in the partial equilibrium there are now two counteracting effects of trade on union wage setting, while in the general equilibrium there is an additional positive effect due to a labor demand stimulus and a higher competitive wage. As noted above, the additional partial equilibrium effects do not change the insights from the benchmark model if the degree of product differentiation is high. However, we cannot be certain that the results in Proposition 3 also extend to small degrees of product differentiation. Shedding light on this issue is the purpose of the following analysis.[14]

[12] While conclusive evidence for learning in the export market is to the best of our knowledge not available, there is strong empirical support for firms focusing on their most successful products when being exposed to competition in the export market (see, for instance, Bernard, Redding, and Schott, 2011, and the literature cited there).

[13] This result differs significantly from Bastos and Kreickemeier (2009) unionized GOLE model with SPFs, where the output gap between non-unionized and unionized firms is more pronounced in the closed than in the open economy.

[14] The Appendix provides a formal characterization of the open economy equilibrium.

| | $w_t^u - w_a^u$ | $w_t^c - w_a^c$ | $\delta_t^u - \delta_a^u$ | $\delta_t^c - \delta_a^c$ | $D_t^u - D_a^u$ | $D_t^c - D_a^c$ | $X_t^u - X_a^u$ | $X_t^c - X_a^c$ |
|---|---|---|---|---|---|---|---|---|
| $\tilde{z} = 0.1$ | -0.17 | 5.55 | -0.02 | -0.06 | -0.61 | -1.96 | 0.67 | 0.02 |
| $\tilde{z} = 0.3$ | 0.24 | 6.78 | -0.03 | -0.07 | -0.73 | -2.29 | 0.66 | -0.16 |
| $\tilde{z} = 0.5$ | 0.90 | 8.50 | -0.03 | -0.08 | -0.91 | -2.72 | 0.61 | -0.42 |

Notes: $D$ denotes domestic firm-level output and subscripts $a$, $t$ refer to autarky and trade variables, respectively. Parameter values are $a = 100$, $b = 1$, $\rho = 0.8$, $n = 5$, $L = 20$.

Table 2.1: Trade effects on wages, scope and scale for different degrees of unionization

Since we are not able to derive sharp analytic results for small degrees of product differentiation, we have conducted a series of numerical simulation exercises to get insights into the trade effects for high levels of $\rho$. Table 2.1 displays the results for $\rho = 0.8$.[15] From the second column of the table we can conclude that for high values of $\rho$ union wage claims may actually fall in response to trade liberalization. But this can only happen if the share of unionized industries is sufficiently small. An intuition for the role of $\tilde{z}$ in determining the impact of trade on union wage claims can be found in Bastos and Kreickemeier (2009). As shown in their study on SPFs, a higher $\tilde{z}$, while not directly affecting the strength of the (partial equilibrium) impact effect on union wage setting in a given industry, implies that this impact effect is relevant for a larger share of sectors, thereby reinforcing the labor demand stimulus of trade and thus the general equilibrium feedback effect through adjustments in $w^c$. From this we can deduce that a positive effect of trade on union wage claims is the more likely, the larger is the share of unionized industries $\tilde{z}$.

Columns 4 and 5 of Table 2.1 present numerical results for the impact of trade on firm scope, and these results indicate that all firms shorten their product range in response to trade, irrespective of the prevailing labor market institutions. The negative effect of trade on firm scope is more pronounced in non-unionized industries, so that, in line with our benchmark model, firms become more similar in this dimension. Furthermore, from inspection of Columns 6 and 7, we can conclude that the findings from our benchmark model regarding the impact of trade on domestic output ($D$) also remain unaffected if one considers relatively high values of $\rho$: All firms reduce their domestic output level in response to trade. However, this does not mean that firm scale falls as well, as firms get access to the export market and thus increase output at the extensive margin. From columns 8 and 9 we see that, in contrast to the benchmark model, the expansion at the extensive margin needs not be strong enough to dominate the output decline at the intensive margin so that the total impact on firm scale is not clearcut in general if $\rho$ is sufficiently large. To be more specific, the numerical results indicate that firm scale definitely increases in unionized industries, while it may increase or fall in non-unionized sectors. In our simulation exercise, firm scale increases in non-unionized industries if $\tilde{z}$ is low, while it declines if $\tilde{z}$ is sufficiently large.

To get an intuition for the role of $\tilde{z}$ in determining the impact of trade on firm scale, it is useful to distinguish two effects. On the one hand, trade induces a general decline in firm scope which leaves more labor for producing high-competence varieties and thus stimulates firm scale in all industries. On the other hand, the wage differential between unionized and non-unionized industries shrinks, which implies that production shifts towards unionized sectors. The stronger

[15] The program code for the simulation exercise (in *Mathematica 8.0*) is deferred to the Appendix.

the latter effect is, the more likely is a negative firm scale effect of trade in non-unionized industries. From inspection of columns 2 and 3 of Table 2.1, we can infer that the reduction in the wage differential is more pronounced for high degrees of unionization. Hence, the second effect dominates if $\tilde{z}$ is sufficiently large. Finally, for all parameter configurations in Table 2.1, the scale differential between unionized and non-unionized industries shrinks in response to a country's movement from autarky to trade, which constitutes a further important difference to our benchmark model (and is in line with the respective findings in Bastos and Kreickemeier, 2009).

We complete the discussion of this chapter by summarizing the main insights from the numerical simulation exercise. For small degrees of product differentiation, a country's movement from autarky to free trade with a symmetric partner country does not necessarily increase firm scale of all producers. Furthermore, the scale differential between firms of non-unionized and unionized industries may shrink in response to trade if $\rho$ is sufficiently large.

## 2.4 Concluding remarks

We have set up a general oligopolistic equilibrium model of MPFs and labor market imperfections due to union wage-setting in a subset of industries. We have used this setting to tackle two questions that have sparked considerable interest of economists in recent years and are of relevance for policy makers alike. The first question we are interested in deals with firm-level (and related economy-wide) adjustments to deunionization, a phenomenon that has been observed in all industrialized countries over the last four decades. Associating deunionization with a reduction in the share of unionized industries, we have shown that deunionization raises both the competitive and the union wage and thus renders a shortening of the product range attractive for MPFs. In addition to the decline in firm scope, the cost increase lowers total output of all interior varieties, so that firm scale decreases in unionized as well as non-unionized industries. With firms concentrating on high-competence varieties, deunionization therefore leads to an increase in labor productivity of all firms (except for the newly deunionized ones). The second question we tackle in this chapter is the impact of trade on firm scale and scope. In this respect, the main insight from our analysis is that, while firms become leaner and meaner as in models of MPFs without labor market frictions, the additional labor force that has been set free by the decline in firm scope is not equally allocated to unionized and non-unionized industries and thus it is not guaranteed that all firms actually increase their scale when being exposed to international trade. To be more specific, with labor market institutions being industry-specific, the firm-level effects of trade depend on a non-trivial interplay of product differentiation and the degree of unionization.

While we hope that our analysis contributes to a better understanding of how MPFs adjust their scale and scope in response to macroeconomic shocks, it is clear that, in the interest of analytical tractability we had to impose several simplifying assumptions which limit the practical relevance of our results. For instance, we have considered a exponential adaptation costs, implying a strictly convex relationship between the distance of a product to the firm's core competence and the unit costs for manufacturing the respective product. To check whether our results are driven by the specific functional form of adaptation costs, we have considered a linear unit cost-distance relationship as an alternative specification in an extension of our baseline model.[16] It turns out that the main insights from our analysis regarding the implications of deunionization and trade liberalization for firm-level variables are not affected by this modifi-

[16]Derivation details are deferred to the Appendix.

cation. In a further extension, we have accounted for firm-level instead of sector-level unions.[17] While in the borderline case of perfect product differentiation, this modification has no impact on our analysis, it renders the formal analysis much more complicated if one accounts for partial product differentiation. However, it is still possible to characterize the autarky as well as the trade equilibrium, and results from numerical simulation exercises indicate that the main insights from our analysis on adjustments in firm scale and scope are robust to this modification.

A further restrictive assumption of our model is the exogenous and equal number of competitors within each industry. This assumption closes one important adjustment margin and restricts our analysis to a short-run perspective. In the long run, it is plausible that firm owners de-invest their capital stock and search for the best investment opportunities in the whole economy. If there are no extra costs of moving capital across sectors, firm owners will adjust their investment strategy in the long run until the return to their investment is the same in all industries. In comparison to our short-run model with an exogenous and equal number of competitors in all industries, this induces a movement of producers towards non-unionized industries. Since non-unionized firms are larger than unionized ones, this gives a labor demand stimulus, thereby raising the competitive as well as the union wage. Hence, compared to our short-run model firm scale and scope shrink in both unionized and non-unionized industries if capital is mobile across industries (at least as long as products are sufficiently differentiated). Another extension of our model which is worthwhile to consider is one that allows for analyzing the consequences of marginal trade liberalization. Since the introduction of trade impediments would significantly complicate our analysis, such a modification is beyond the scope of this chapter. However, we can follow Eckel and Neary (2010) and associate marginal steps of trade liberalization with an increase in the number of trading partners. In the case of perfect product differentiation, opening up for trade with an additional (symmetric) partner country reinforces the respective effects identified in the previous chapter. While this result can be extended to sufficiently high degrees of (partial) product differentiation, determining the respective effects for arbitrary levels of $\rho$ is not a trivial task and, hence, we leave a more detailed discussion of this issue open for future research.

[17] Derivation details are deferred to the Appendix.

## 2.5 Appendix

### The link between wages and firm scale and scope

Applying the implicit function theorem to (2.9) gives

$$\frac{d\delta(z)}{dw(z)} = -\frac{1}{w(z)} \frac{e^{\delta(z)}\big(1+\phi\delta(z)-\phi\big)+\phi}{e^{\delta(z)}(1+\phi\delta(z))} < 0. \tag{2.13}$$

Furthermore, substituting (2.9) into (2.8) and differentiating the resulting expression with respect to $w(z)$ gives

$$\frac{dX(z)}{dw(z)} = -\frac{e^{\delta(z)}-1}{2b(1-\rho)[1+\phi\delta(z)]} < 0. \tag{2.14}$$

This proves the respective statements in the main text. *QED.*

### The link between the competitive wage and the union wage

To show that a higher competitive wage provides a stimulus for the union wage, i.e. $dw^u/dw^c > 0$, we can define the implicit function

$$\Gamma(w^c, w^u) \equiv w^u - \frac{1}{2}w^c - \frac{a}{(1+\phi\delta^u)(e^{\delta^u}-1)}\left[1-\frac{w^c}{w^u}\right] = 0, \tag{2.15}$$

according to (2.11). Partially differentiating $\Gamma(\cdot)$ with respect to $w^c$ and accounting for $a/w^u = e^{\delta^u}(1+\phi\delta^u-\phi)+\phi$, according to (2.9), we obtain

$$\frac{\partial\Gamma(\cdot)}{\partial w^c} = \frac{(e^{\delta^u}+1)(1+\phi\delta^u)-2\phi(e^{\delta^u}-1)}{2(1+\phi\delta^u)(e^{\delta^u}-1)}, \tag{2.16}$$

which is positive.[18] Partially differentiating $\Gamma(\cdot)$ with respect to $w^u$ gives

$$\frac{\partial\Gamma(\cdot)}{\partial w^u} = 1 - \frac{w^c}{w^u}\frac{a/w^u}{(1+\phi\delta^u)(e^{\delta^u}-1)} + \left(1-\frac{w^c}{w^u}\right)\frac{a\left[e^{\delta^u}(1+\phi\delta^u)+\phi\left(e^{\delta^u}-1\right)\right]}{(1+\phi\delta^u)^2\left(e^{\delta^u}-1\right)^2}\frac{d\delta^u}{dw^u}. \tag{2.17}$$

Using (2.13) and substituting $a/w^u = e^{\delta^u}(1+\phi\delta^u-\phi)+\phi$, we can further calculate

$$\frac{\partial\Gamma(\cdot)}{\partial w^u} = -\left[(\alpha^2\beta-1)-\frac{w^c}{w^u}(\alpha^2\beta-\alpha)\right], \tag{2.18}$$

with

$$\alpha \equiv \frac{e^{\delta^u}(1+\phi\delta^u)-\phi\left(e^{\delta^u}-1\right)}{(e^{\delta^u}-1)(1+\phi\delta^u)}, \qquad \beta \equiv \frac{e^{\delta^u}(1+\phi\delta^u)+\phi\left(e^{\delta^u}-1\right)}{e^{\delta^u}(1+\phi\delta^u)} > 1. \tag{2.19}$$

Hence, $\alpha > 1$, which is equivalent to $1-\phi(e^{\delta^u}-\delta^u-1) > 0$, is sufficient for $\partial\Gamma(\cdot)/\partial w^u < 0$. Using (2.9) together with (2.11), we can conclude that $1-\phi(e^{\delta^u}-\delta^u-1) > 0$ is equivalent to $\omega > 1$, so that $\partial\Gamma(\cdot)/\partial w^u < 0$ and, by applying the implicit function theorem to (2.15), also $dw^u/dw^c > 0$ are immediate.

[18]It is immediate that the denominator of this expression is positive, while the numerator is strictly increasing in $\delta^u$ and equals 2 at $\delta^u = 0$.

## Proof of Proposition 1

Let us first differentiate $f(z) \equiv w(z)[e^{\delta(z)} - 1]^2$ with respect to $w(z)$. Accounting for (2.13), this gives[19]

$$\frac{df(z)}{dw(z)} = -\frac{e^{\delta(z)} - 1}{1 + \phi\delta(z)} \left[ (e^{\delta(z)} + 1)(1 + \phi\delta(z)) - 2\phi(e^{\delta(z)} - 1) \right] < 0. \tag{2.20}$$

This implies $w^u(e^{\delta^u} - 1)^2 < w^c(e^{\delta^c} - 1)^2$, so that the right-hand side of (2.12) unambiguously falls in $\tilde{z}$, when holding wages constant. Furthermore, combining $df(z)/dw(z) < 0$ with $dw^u/dw^c > 0$, we can conclude that the right-hand side of (2.12) determines a negative relationship between economy-wide labor demand and the competitive wage $w^c$. Applying the implicit function theorem to Eq. (2.12), we therefore get $dw^c/d\tilde{z} < 0$, $dw^u/d\tilde{z} < 0$, which, in view of $d\delta(z)/dw(z) < 0$ and $dX(z)/dw(z) < 0$ (see Eqs. (2.13) and (2.14)), establishes a positive relationship between $\tilde{z}$ and the scale and scope of MPFs. Finally, substituting $x(i,z)$ from (2.6′) into $l(z) = \int_0^{\delta(z)} e^i x(i,z)di$, gives $l(z) = w(z)\left(e^{\delta(z)} - 1\right)^2/[4b(1-\rho)]$. Using the latter together with Eq. (2.8) $X(z)/l(z)$ gives labor productivity, $\xi$, as a function of firm scope:

$$\xi(z) = 2\frac{e^{\delta(z)}\left(\delta(z) - 1\right) + 1}{\left(e^{\delta(z)} - 1\right)^2} \tag{2.21}$$

It is straightforward to show that $d\xi(z)/d\delta(z) < 0$, so that $d\xi(z)/d\tilde{z} < 0$ is immediate. This completes the proof of Proposition 1. *QED.*

## Deunionization and the number of product varieties when $\rho = 0$

The total number of product varieties is given by $N \equiv \tilde{z}N^u + (1-\tilde{z})N^c = \tilde{z}n\delta^u + (1-\tilde{z})n\delta^c$. Differentiating the latter with respect to $\tilde{z}$, we obtain

$$\frac{dN}{d\tilde{z}} = n\left\{ \ln\left(\frac{1}{\omega}\right) - \frac{dw^c}{d\tilde{z}}\left[ \tilde{z}\frac{1}{w^u}\frac{a + w^u}{4w^u - w^c} + (1-\tilde{z})\frac{1}{w^c} \right] \right\}, \tag{2.22}$$

according to (2.7).[20] Totally differentiating (2.12) and accounting for $a/w^u = 2\omega - 1$, $a/w^c = \omega(2\omega - 1)$ from (2.11)[21], we can calculate

$$\frac{dw^c}{d\tilde{z}} = w^c \frac{4\omega(\omega-1)^2 - [\omega(2\omega-1) - 1]^2}{8\tilde{z}\omega^3(4\omega-1)^{-1}(\omega-1) + (1-\tilde{z})[(\omega(2\omega-1))^2 - 1]}. \tag{2.23}$$

Substituting the latter into (2.22), we get

$$\frac{dN}{d\tilde{z}} = n\left\{ \ln\left(\frac{1}{\omega}\right) - \frac{\left\{4\omega(\omega-1)^2 - [\omega(2\omega-1)-1]^2\right\}\left[2\tilde{z}\omega(4\omega-1)^{-1} + (1-\tilde{z})\right]}{8\tilde{z}\omega^3(4\omega-1)^{-1}(\omega-1) + (1-\tilde{z})[(\omega(2\omega-1))^2 - 1]} \right\}. \tag{2.24}$$

Evaluating $dN/d\tilde{z}$ at $\tilde{z} = 0$ gives

$$\left.\frac{dN}{d\tilde{z}}\right|_{\tilde{z}=0} = n\left[ \ln\left(\frac{1}{\omega}\right) - \frac{4\omega(\omega-1)^2 - [\omega(2\omega-1)-1]^2}{[(\omega(2\omega-1))^2 - 1]} \right], \tag{2.25}$$

[19] For a negative sign of (2.20) the bracket term on the right-hand side of this equation must be positive. To show that this is the case, we can differentiate the bracket term and obtain $e^{\delta(z)}\left(1 + \phi\delta(z) - \phi\right) + \phi = a/w^u > 0$. Furthermore, evaluating the bracket term at $\delta(z) = 0$ gives 2. Hence, we can safely conclude that the bracket term is positive for any $\delta(z) > 0$.

[20] Note that with $\rho = 0$ total firm scope reads $\delta(z) = \ln[a/w(z)]$.

[21] With $\rho = 0$ we have $w^u = 1/2\,[w^c + a/\omega]$.

which is negative for any $\omega > 1$. Evaluating $dN/d\tilde{z}$ at $\tilde{z} = 1$ gives

$$\left.\frac{dN}{d\tilde{z}}\right|_{\tilde{z}=1} = n\left[\ln\left(\frac{1}{\omega}\right) - \frac{\omega-1}{\omega} + \frac{[\omega(2\omega-1)-1]^2}{4\omega^2(\omega-1)}\right], \tag{2.26}$$

which is positive for any $\omega > 1$. This proves the respective statement in the main text. *QED.*

## Welfare effects of deunionization when $\rho = 0$

Setting $\rho = 0$ and accounting for $\lambda = 1$, we can rewrite (2.4) in the following way: $q(i,z) = \frac{1}{b}[a - \lambda p(i,z)]$. Substituting the latter into (2.2), gives $u\{z\} = [n/(2b)]\left[a^2\delta(z) - \int_0^{\delta(z)} p(i,z)^2\right]$ and, accounting for $p(i,z) = (1/2)[a + w(z)e^i]$, we can calculate

$$u\{z\} = \frac{n}{16b}\left[6a^2\ln[\frac{a}{w(z)}] - 4a^2 + 4aw(z) - a^2 + w(z)^2\right]. \tag{2.27}$$

And adding over all industries, we thus get

$$\begin{aligned} U = &\frac{n}{16b}\tilde{z}\left[6a^2\ln[\frac{a}{w^u}] - 4a^2 + 4aw^u - a^2 + (w^u)^2\right] \\ &+ \frac{n}{16b}(1-\tilde{z})\left[6a^2\ln[\frac{a}{w^c}] - 4a^2 + 4aw^c - a^2 + (w^c)^2\right] \end{aligned} \tag{2.28}$$

Differentiating the latter with respect to $\tilde{z}$

$$\begin{aligned} \frac{dU}{d\tilde{z}} = &\frac{n}{16b}\left\{6(w^c)^2\left(\frac{a}{w^c}\right)^2\ln\left(\frac{1}{\omega}\right) + (w^c)^2\left(4\frac{a}{w^c}\omega + \omega^2 - 4\frac{a}{w^c} - 1\right) + \right. \\ &\left. + \frac{dw^c}{d\tilde{z}}\left[\tilde{z}\frac{dw^u}{dw^c}w^u\left(4\frac{a}{w^u} + 2 - 6\left(\frac{a}{w^u}\right)^2\right) + (1-\tilde{z})w^c\left(4\frac{a}{w^c} + 2 - 6\left(\frac{a}{w^c}\right)^2\right)\right]\right\} \end{aligned} \tag{2.29}$$

Using $a/w^u = 2\omega - 1$ and $a/w^c = \omega(2\omega-1)$ and $dw^u/dw^c = (a+w^u)/4w^u - w^c) = 2\omega^2/(4\omega-1)$, further implies

$$\begin{aligned} \frac{dU}{d\tilde{z}} = &\frac{n}{16b}\left\{(w^c)^2\left(24\omega^4 - 24\omega^3 + 6\omega^2\right)\ln\left(\frac{1}{\omega}\right) + (w^c)^2\left(8\omega^3 - 11\omega^2 + 4\omega - 1\right)\right. \\ &\left. + \frac{dw^c}{d\tilde{z}}w^c\left[\tilde{z}\frac{2\omega^3}{4\omega-1}\left(-24\omega^2 + 32\omega - 8\right) + (1-\tilde{z})\left(-24\omega^4 + 24\omega^3 + 2\omega^2 - 4\omega + 2\right)\right]\right\} \end{aligned}$$

And substituting

$$\frac{dw^c}{d\tilde{z}} = w^c\frac{4\omega(\omega-1)^2 - [\omega(2\omega-1)-1]^2}{8\tilde{z}\omega^3(\omega-1)(4\omega-1)^{-1} + (1-\tilde{z})[(\omega(2\omega-1))^2 - 1]} \tag{2.30}$$

we finally arrive at

$$\begin{aligned} \frac{dU}{d\tilde{z}} = &\frac{n}{16b}(w^c)^2\left\{\left(24\omega^4 - 24\omega^3 + 6\omega^2\right)\ln\left(\frac{1}{\omega}\right) + 8\omega^3 - 11\omega^2 + 4\omega - 1\right. \\ &\left. + \left[\tilde{z}\frac{2\omega^3}{4\omega-1}\left(-24\omega^2 + 32\omega - 8\right) + (1-\tilde{z})\left(-24\omega^4 + 24\omega^3 + 2\omega^2 - 4\omega + 2\right)\right]\rho(\omega)\right\}, \end{aligned} \tag{2.31}$$

with $\rho(\omega) \equiv dw^c/d\tilde{z} \times (w^c)^{-1}$.

Evaluating the latter at $\tilde{z} = 0$, gives

$$\left.\frac{dU}{d\tilde{z}}\right|_{\tilde{z}=0} = \frac{n}{16b}(w^c)^2 \Bigg\{ \left(24\omega^4 - 24\omega^3 + 6\omega^2\right) \ln\left(\frac{1}{\omega}\right) + 8\omega^3 - 11\omega^2 + 4\omega - 1 + \left[24\omega^4 - 24\omega^3 - 2\omega^2 + 4\omega - 2\right] \frac{(4\omega^2+1)(\omega-1)}{4\omega^3+\omega+1} \Bigg\}, \tag{2.32}$$

which is negative for any $\omega > 1$. Furthermore, evaluating $dU/d\tilde{z}$ at $\tilde{z} = 1$, gives

$$\left.\frac{dU}{d\tilde{z}}\right|_{\tilde{z}=1} = \frac{n}{16b}(w^c)^2 \Bigg\{ \left(24\omega^4 - 24\omega^3 + 6\omega^2\right) \ln\left(\frac{1}{\omega}\right) + 8\omega^3 - 11\omega^2 + 4\omega - 1 + \left(6\omega^2 - 8\omega + 2\right)(4\omega^2+1)(\omega-1) \Bigg\}, \tag{2.33}$$

which can shown to be positive for any $\omega > 1$. This completes the proof. *QED.*

## Proof of Proposition 2

Let us first consider the benchmark case of $\rho = 0$, which implies $\phi = 0$. Rearranging terms in (2.11) and accounting for $\phi = 0$, we can calculate $w^c = (a/\omega)(2\omega - 1)^{-1}$, with $\omega = w^u/w^c$ and $d\omega/dw^c < 0$. Noting $dw^c/d\tilde{z} < 0$ from Proposition 1, this implies $d\omega/d\tilde{z} > 0$. Furthermore, substituting $\delta(z)$ from (2.9) into $\Delta = \delta^c - \delta^u$ and evaluating the resulting expression at $\rho = 0$, gives $\Delta = \ln(\omega)$, with $d\Delta/d\omega > 0$ and, in view of $d\omega/d\tilde{z} > 0$, also $d\Delta/d\tilde{z} > 0$. Finally, substituting (2.8) into $\Xi = X^c - X^u$ and evaluating the resulting expression at $\rho = 0$, we can calculate

$$\Xi = \frac{a}{2b}\left[\ln(\omega) - \frac{\omega - 1}{\omega(2\omega - 1)}\right] \tag{2.34}$$

Differentiating the latter with respect to $\omega$ and evaluating the resulting expression at $\omega > 1$, gives $d\Xi/d\omega > 0$.We can thus safely conclude that $d\Xi/d\tilde{z} > 0$.

Unfortunately, we are not able to show that the insights from the benchmark scenario with perfect product differentiation ($\rho = 0$) extend to the more general case of partial product differentiation, when allowing for arbitrary levels of $\rho$. However, with all variables of interest being continuously differentiable in $\rho$, we can at least conclude that the respective insights from the benchmark scenario are robust to small changes in $\rho$. This completes the proof of Proposition 2. *QED.*

## Proof of Proposition 3

Let us first consider the benchmark case of $\rho = 0$. With firms being a monopolist in all submarkets of their production, opening up to trade leaves Eqs. (2.6′), (2.7) and (2.11) unaffected. Furthermore, with firms serving two instead of just a single market total firm output is given by $X(z) = 2D(z)$ in the open economy, where $D(z)$ equals local output in (2.8), when setting $\rho = 0$. As a consequence, labor demand, as determined on the right-hand side of (2.12), doubles for any wage configuration. This implies that $w^c$ and $w^u$ must increase to restore labor market clearing (see the formal discussion in the closed economy). With $w^c$ and $w^u$ increasing, firm scope and domestic output must fall, according to (2.13) and (2.14). Furthermore, labor productivity increases, according to (2.21).

To determine the impact of trade on total firm scale $X(z)$, we can make use of the following fact: The impact of trade on $X(z)$ is qualitatively the same as the impact of trade on $Y(z) \equiv \hat{n}X(z)$, where $\hat{n} = n$ under autarky and $\hat{n} = 2n$ under free trade. Differentiating $Y(z)$ with respect to $\hat{n}$, accounting for (2.8) and setting $\rho = 0$, we can calculate

$$\frac{dY(z)}{d\hat{n}} = \frac{1}{2b}\left\{a\left[\ln\left(\frac{a}{w(z)}\right)-1\right] + w(z) - w(z)\left(\frac{a}{w(z)}-1\right)\frac{\hat{n}}{w(z)}\frac{dw(z)}{d\hat{n}}\right\}. \tag{2.35}$$

Distinguishing between non-unionized and unionized industries, accounting for $a/w^c = \omega(2\omega-1)$ and $a/w^u = 2\omega - 1$, according to (2.11), and using $dw^c/d\hat{n} = (w^c/\hat{n})\beta(\omega)$, with

$$\beta(\omega) \equiv \frac{4\tilde{z}\omega(\omega-1)^2 + (1-\tilde{z})\left[\omega(2\omega-1)-1\right]^2}{8\tilde{z}\omega(\omega-1)^2\omega^2/\left[4\omega^2-5\omega+1\right] + (1-\tilde{z})\left[\omega(2\omega-1)-1\right]\left[\omega(2\omega-1)+1\right]}, \tag{2.36}$$

according to (2.12), the latter can be rewritten as

$$\frac{dY^c}{d\hat{n}} = \frac{w^c}{2b}\left\{\omega(2\omega-1)\Big[\ln\Big(\omega(2\omega-1)\Big)-1\Big] + 1 - \Big[\omega(2\omega-1)-1\Big]\beta(\omega)\right\}, \tag{2.37}$$

$$\frac{dY^u}{d\hat{n}} = \frac{w^c}{2b}\left\{\omega(2\omega-1)\Big[\ln\Big(2\omega-1\Big)-1\Big] + \omega - \frac{4(\omega-1)\omega^2}{4\omega-1}\beta(\omega)\right\}, \tag{2.38}$$

respectively. It is tedious but straightforward to show that the right-hand sides of (2.37) and (2.38) are positive, implying that $dY^c/d\hat{n} > 0$, $dY^u/d\hat{n} > 0$.

Noting from the analysis of the closed economy that $\Delta = \ln(\omega)$ if $\rho = 0$ and recollecting from above that $\omega$ shrinks if $w^c$ increases, it is immediate that the scope differential declines in response to a country's movement form autarky to free trade with a symmetric partner economy. In a further step, we now look at the impact of trade on firm size differential $\Xi$. Noting that, with a constant number of competitors in either country, changes in $\Xi$ are qualitatively the same as changes in $\Psi \equiv Y^c - Y^u$, we can conclude from Eqs. (2.37) and (2.38) that $d\Xi/d\hat{n} >,=,< 0$ is equivalent to $[4\omega-1]\big[\omega(2\omega-1)\ln(\omega)-(\omega-1)\big]-(\omega-1)\big(4\omega^2+2\omega-1\big)\beta(\omega) >,=,< 0$. Furthermore, taking into account $\beta(\omega)$ is increasing in $\tilde{z}$ and that $\beta(\omega)|_{\tilde{z}=1} = \big[4\omega^2-5\omega+1\big]/(2\omega^2)$, we can further conclude that $\zeta(\omega) \equiv 2\omega^2\big[\omega(2\omega-1)\ln(\omega)-(\omega-1)\big]-(\omega-1)^2\big(4\omega^2+2\omega-1\big) > 0$ is sufficient for $d\Xi/d\hat{n} > 0$.[22]

Noting finally that the variables of interest are continuously differentiable in $\rho$, we can conclude that the insights from above are robust to small changes in $\rho$. This completes the proof of Proposition 3. *QED.*

## Characterization of the open economy equilibrium: the case of $\rho > 0$

In the open economy, a firm's domestic output, $D(z)$, is given by Eq. (2.8). Due to symmetry of trading partners, a similar expression is obtained for the foreign economy: $D^*(z)$, where the asterisk is introduced to indicate foreign variables. Total sector output in the open economy is

[22] Differentiating $\zeta(\omega)$ three times gives $\zeta'''(\omega) = 96\omega\ln(\omega) - 12\ln(\omega) + 8\omega + 2 > 0$. Together with $\zeta''(1) = 0$, this proves that the second derivative of $\zeta(\cdot)$ is strictly positive for any $\omega > 1$. Noting further that $\zeta'(1) = 0$, we can also conclude that the first derivative of $\zeta(\cdot)$ is strictly positive for any $\omega > 1$. Noting finally that $\zeta(1) = 0$, therefore proves that $\zeta(\cdot)$ has a positive sign for any $\omega > 1$.

then given by $Y(z) = nD(z) + nD^*(z)$. Substituting the latter together with (2.8) – separately for the home and the foreign country – into (2.7) and noting that in the open economy $D(z)$ assumes the role that $X(z)$ had in the closed economy, we can calculate

$$e^{\delta(z)} = \frac{1}{w(z)} \frac{a - w(z)\phi - w^*(z)\phi[n/(n+1)][e^{\delta^*(z)}(\delta^*(z)-1)+1]}{1+\phi\delta(z)-\phi}, \tag{2.39}$$

$$e^{\delta^*(z)} = \frac{1}{w^*(z)} \frac{a - w^*(z)\phi - w(z)\phi[n/(n+1)][e^{\delta(z)}(\delta(z)-1)+1]}{1+\phi\delta^*(z)-\phi} \tag{2.40}$$

for domestic and foreign firms' scope, respectively. Thereby, $\phi = \rho(n+1)/[2(1-\rho)]$ is the same as in the closed economy. In the case of symmetry, with $\delta^u = \delta^{u*}$ and $w^u = w^{u*}$, Eq. (2.39) can be simplified to

$$\delta(z) = \ln\left[\frac{a/w(z) - \phi(2n+1)/(n+1)}{1+\phi(\delta(z)-1)(2n+1)/(n+1)}\right]. \tag{2.41}$$

Equipped with these insights we can now solve the wage-setting problem of labor unions. Following the steps from the analysis in the closed economy and using $e^{\delta^u}$ from (2.39) instead of (2.9), we can calculate the first-order condition for the $\Omega$-maximization problem as follows

$$\frac{d\Omega}{dw^u} = \frac{n(e^{\delta^u}-1)}{2b(1-\rho)}\left[(2w^u - w^c)\left(e^{\delta^u}-1\right) + 2w^u(w^u-w^c)e^{\delta^u}\frac{d\delta^u}{dw^u}\right] = 0. \tag{2.42}$$

Applying the implicit function theorem to system (2.39), (2.40) and evaluating the resulting expression at $\delta^u = \delta^{u*}$ (symmetry), we get

$$\frac{d\delta^u}{dw^u} = -\frac{1}{w^u}\frac{\left[e^{\delta^u}(1+\phi\delta^u-\phi)+\phi\right](1+\phi\delta^u) - \phi^2[n/(n+1)]^2\left[e^{\delta^u}(\delta^u-1)+1\right]\delta^u}{e^{\delta^u}\left[(1+\phi\delta^u)^2 - (\phi\delta^u)^2[n/(n+1)]^2\right]}. \tag{2.43}$$

Substituting (2.43) into (2.42), we obtain after tedious but straightforward calculations:

$$w^u = w^c\left(\frac{1}{2}\,\frac{(e^{\delta^u}-1)}{1-e^{\delta^u}+H(\delta^u)}+1\right), \tag{2.44}$$

where

$$H(\delta^u) \equiv \frac{(1+\phi\delta^u)\left[e^{\delta^u}(1+\phi\delta^u-\phi)+\phi\right] - \phi^2\delta^u[n/(n+1)]^2\left[e^{\delta^u}(\delta^u-1)+1\right]}{(1+\phi\delta^u)^2 - \left[\phi\delta^u[n/(n+1)]\right]^2}. \tag{2.45}$$

Finally, we can write the full employment condition as follows

$$L = \frac{n}{2b(1-\rho)}\left[\tilde{z}w^u\left(e^{\delta^u}-1\right)^2 + (1-\tilde{z})w^c\left(e^{\delta^c}-1\right)^2\right]. \tag{2.46}$$

Putting all elements together, the open economy equilibrium is characterized by (2.8), (2.41) – separately for $u$ and $c$ –, (2.44), and (2.46). This completes the characterization of the open economy.

### 2.5.1 Extension – Linear cost function

In the main text, we represent adaptation costs by an exponential unit cost-density function. In this extension, we check the robustness of our results when changing our assumption, regarding the functional form of adaptation costs. To be more specific, we consider the linear specification $\gamma_j(i) = 1 + i$, and investigate whether the main insights from our analysis remain the same in this modified framework. To keep the analysis tractable, we focus on a benchmark scenario with $\rho = 0$ throughout the subsequent discussion.

With a linear cost specification, product-specific output and the product range are given by

$$x_j(i,z) = \frac{a - (1+i)w(z)}{2b} \qquad \delta_j(i,z) = \frac{a}{w(z)} - 1 \tag{2.47}$$

instead of (2.6) and (2.7), while product-specific output relative to the marginal good is given by

$$x_j(i,z) = \frac{w(z)[\delta(z) - i]}{2b} \tag{2.48}$$

instead of (2.6′). Integrating $x_j(i,z)$ over all varieties gives, after straightforward calculations, total firm output $X_j(z) = w(z)\delta(z)^2/(4b)$. To calculate firm-level labor demand $l_j(z)$ we use (2.48) in $l_j(z) = \int_0^{\delta(z)} x_j(i,z)\gamma(i)di$ and obtain $l_j(z) = a\left[(a/w(z))^2 - 3 + 2w(z)/a\right]/(12b)$.

With these insights at hand, we are now well equipped to calculate the union wage. For this purpose, we substitute $l_j(z)$ into the union objective function $\Omega = [w(z) - w^c]nl(z)$ (and suppress firm indices in the interest of better readability). Differentiating $\Omega$ with respect to $w^u$ and setting the resulting expression equal to zero, we can calculate[23]

$$w^u = 2w^c \frac{(\delta^u)^2 + 3\delta^u + 3}{(\delta^u)^2 + 3\delta^u + 6}. \tag{2.49}$$

Furthermore, accounting for $\delta^u = a/w^u - 1$, we can rewrite (2.49) as follows

$$w^u = 2w^c \frac{a^2 + aw^u + (w^u)^2}{a^2 + aw^u + 4(w^u)^2}. \tag{2.50}$$

Applying the implicit function theorem, we can furthermore calculate

$$\frac{dw^u}{dw^c} = 2\frac{a^2 + aw^u + (w^u)^2}{a^2 + 2a(w^u - w^c) + 4w^u(3w^u - w^c)}. \tag{2.51}$$

Hence, (2.50) establishes a positive relationship between $w^c$ and $w^u$.

Before turning to the general equilibrium outcome, it is worth inspecting the firm scale and scope differential between non-unionized and unionized firms. The scope differential is given by $\Delta = \delta^c - \delta^u = a/w^c - a/w^u$, which, in view of (2.47), can be rewritten as

$$\Delta = [1 + \delta^c]\left[1 - \frac{1}{\omega}\right], \tag{2.52}$$

which is unambiguously positive, as $w^u > w^c$ and thus $\omega > 1$. The scale differential is given by $\Xi = X^c - X^u = \left[w^c(\delta^c)^2 - w^u(\delta^u)^2\right]/(4b)$ and, accounting for (2.47), we can calculate

$$\Xi = \frac{w^c}{4b}\left[\frac{a}{w^c}(\delta^c - \delta^u) + 1 - \omega\right], \tag{2.53}$$

[23] Noting that $[(\delta^u)^2 + 3\delta^u + 3]/[(\delta^u)^2 + 3\delta^u + 6] \geq 1/2$, we can easily confirm that $w^u \geq w^c$.

which is positive as $a > w^u > w^c$.[24]

The general equilibrium outcome is characterized by the labor market clearing condition $L = \int_0^1 \int_0^{\delta(z)} nx(i,z)\gamma(i)didz = n\int_0^1 l(z)dz$. Rearranging terms, we get[25]

$$L = \frac{an}{12b}\left\{\tilde{z}\left[\left(\frac{a}{w^u}\right)^2 - 3 + 2\frac{w^u}{a}\right] + (1-\tilde{z})\left[\left(\frac{a}{w^c}\right)^2 - 3 + 2\frac{w^c}{a}\right]\right\} \tag{2.54}$$

We are now prepared to study the implications of deunionization in the closed economy. In analogy to the model variant in the main text, a decrease in $\tilde{z}$ raises economy-wide labor demand and hence $w^c$ must increase in order to restore a labor market equilibrium. Formally, this can be shown by applying the implicit function theorem to (2.54). Furthermore, a higher competitive wage provides a stimulus for the union wage, according to (2.51), so that $w^u$ also increases in response to a decline in $\tilde{z}$. Due to these wage effects, it is immediate that unionized as well as non-unionized firms lower the scope in response to deunionization, i.e. $\delta^c$ and $\delta^u$ decrease, according to (2.47). Accounting for

$$X(z) = \frac{w(z)}{4b}\delta(z)^2 = \frac{1}{4b}\left[\frac{a^2}{w(z)} - 2a + w(z)\right] \tag{2.55}$$

it is straightforward to show that both $X^c$ and $X^u$ decline in response to deunionization, i.e. all firms, except of the newly deunionized ones, shrink if $\tilde{z}$ falls.

Aside from these firm-level effects, we can also analyze the differential impact of deunionization on unionized and non-unionized firms. For this purpose, we can first analyze the impact of a decline in $\tilde{z}$ on $\omega$. From (2.49)

$$\omega = 2\frac{(\delta^u)^2 + 3\delta^u + 3}{(\delta^u)^2 + 3\delta^u + 6}. \tag{2.56}$$

Since the right-hand side of the latter increases in $\delta^u$, it follows from our insights above that a decline in $\tilde{z}$ induces a fall in $\omega$. However, since $w^c$ increases while $\omega$ falls in response to deunionization, it follows from (2.52) that the scope differential between non-unionized and unionized producers shrinks if $\tilde{z}$ declines. With firms concentrating more on their core competence products, labor productivity is stimulated by deunionization in our model. Regarding the impact of deunionization on the firm scale differential, it is worth noting that (2.55) implies

$$\Xi = \frac{1}{4b}\left[\frac{a^2}{w^c}\left(1 - \frac{1}{\omega}\right) + w^c(1-\omega)\right] \tag{2.57}$$

Differentiating $\Xi$ with respect to $\tilde{z}$, then implies

$$\frac{d\Xi}{d\tilde{z}} = \frac{1}{4b}\left\{\left[-\left(\frac{a}{w^c}\right)^2\left(1 - \frac{1}{\omega}\right) + 1 - \omega\right]\frac{dw^c}{d\tilde{z}} + w^c\left[\left(\frac{a}{w^u}\right)^2 - 1\right]\frac{d\omega}{d\tilde{z}}\right\}. \tag{2.58}$$

[24] To see this, note that $(1+\delta^c)(\delta^c - \delta^u) = (1+\delta^c)^2(1-1/\omega)$, according to (2.52). Hence, $\Xi > 0$ is equivalent to $(1+\delta^c)^2 > \omega$ and, in view of (2.47), equivalent to $(a/w^c)^2 > w^u/w^c$. This implies that $a > w^u > w^c$ is sufficient for $\Xi > 0$.

[25] Defining $f(z) \equiv a^3/w(z)^2 - 3a + 2w(z)$ and accounting for $\partial f(z)/\partial w(z) = 2[1-(a/w(z))^3] < 0$, it is easily confirmed that the right-hand side ($RHS$, in short) of (2.54) is strictly decreasing in $w^c$. Furthermore, noting that $\lim_{w^c \to 0} RHS = \infty$, while $\lim_{w^c \to a} RHS = 0$, we can safely conclude that there exists a unique equilibrium with factor market clearing in our model.

And noting $dw^c/d\tilde{z} < 0$, $d\omega/d\tilde{z} > 0$ from above, we can conclude that the firm size differential shrinks if $\tilde{z}$ declines. This completes our discussion upon firm-level adjustments in response to deunionization. And we can now turn to analyzing the open economy.[26]

Similar to the scenario with an exponential cost-distance function, trade raises economy-wide labor demand, so that $w^c$ increases. This provides a stimulus for $w^u$, while $\delta^u$ and $\delta^c$ shrink. As firms produce less varieties their productivity increases. Furthermore, similar to the model variant in the main text, we find that any firm's total domestic sales, $D(z)$, shrink, that $\omega$ falls and that the scope differential, $\Delta$, decreases. To analyze the impact on total firm output we follow the analysis in the main text and note that the impact of trade on total firm output can be inferred from $dY/d\hat{n}$, where

$$Y(z) = \hat{n}X(z) = \frac{\hat{n}}{4b}w(z)\left[\frac{a}{w(z)} - 1\right]^2 \tag{2.59}$$

is industry-wide output. Straightforward calculations give

$$\frac{dY(z)}{d\hat{n}} = \frac{1}{4b}w(z)\left[\frac{a}{w(z)} - 1\right]^2 + \frac{\hat{n}}{4b}\frac{dw(z)}{d\hat{n}}\left[1 - \left(\frac{a}{w(z)}\right)^2\right]. \tag{2.60}$$

And, following the derivation in the main text step by step, we arrive at

$$\frac{dY^c}{d\hat{n}} = \frac{1}{4b}w^c\left[\frac{a}{w^c} - 1\right]^2 + \frac{1}{4b}\frac{g(w^c)}{g'(w^c)}\left[\left(\frac{a}{w^c}\right)^2 - 1\right], \tag{2.61}$$

where

$$g(w^c) \equiv \tilde{z}a\left[\left(\frac{a}{w^u}\right)^2 - 3 + 2\frac{w^u}{a}\right] + (1-\tilde{z})a\left[\left(\frac{a}{w^c}\right)^2 - 3 + 2\frac{w^c}{a}\right] > 0 \tag{2.62}$$

and

$$g'(w^c) = 2\tilde{z}\frac{dw^u}{dw^c}\left[1 - \left(\frac{a}{w^u}\right)^3\right] + 2(1-\tilde{z})\left[1 - \left(\frac{a}{w^c}\right)^3\right] < 0. \tag{2.63}$$

We can thus conclude that $dY^c/d\hat{n} >,=,< 0$ is equivalent to

$$0 >,=,< w^c\left[\frac{a}{w^c} - 1\right]^2 g'(w^c) + g(w^c)\left[\left(\frac{a}{w^c}\right)^2 - 1\right] \tag{2.64}$$

Accounting for $g(w^c)$ and $g'(w^c)$ from above and substituting $\kappa \equiv a/w^u$, we can further note that $dY^c/d\hat{n} >,=,< 0$ is equivalent to

$$\begin{aligned} 0 >,=,<\tilde{z} &\left[\omega\left(\kappa^3 - 3\kappa + 2\right)(\kappa\omega + 1) - 2\left(\kappa^3 - 1\right)(\kappa\omega - 1)\frac{dw^u}{dw^c}\right] \\ &+ (1-\tilde{z})\left[\left(\kappa^3\omega^3 - 3\kappa\omega + 2\right)(\kappa\omega + 1) - 2\left(\kappa^3\omega^3 - 1\right)(\kappa\omega - 1)\right], \end{aligned} \tag{2.65}$$

[26] We have also analyzed the impact of deunionization on the total number of available product varieties $N$. While we do not present details of this analysis here, it is worth noting that similar to the main text, deunionization does not exert a monotonic impact on $N$. To be more specific, our results indicate that $N$ increases in response to deunionization if $\tilde{z}$ has been small initially, while the opposite is true if $\tilde{z}$ has been large prior to the deunionization shock.

when taking into account that $\kappa > 1$, $\omega > 1$ must hold by construction. Substituting

$$\frac{dw^u}{dw^c} = 2\frac{\kappa^2+\kappa+1}{\kappa^2+2\kappa+12-2\kappa/\omega-4/\omega}, \tag{2.66}$$

according to (2.51), we can finally conclude that $dY^c/d\hat{n} >,=,< 0$ is equivalent to $0 >,=,< T_1 + T_2$, with

$$T_1 \equiv \tilde{z}\left(\kappa\omega-1\right)\omega\left[\left(\kappa^3-3\kappa+2\right)\left(\kappa\omega+1\right)-4\frac{\left(\kappa^3-1\right)\left(\kappa\omega-1\right)\left(\kappa^2+\kappa+1\right)}{\kappa^2\omega+2\kappa\omega+12\omega-2\kappa-4}\right], \tag{2.67}$$

$$T_2 \equiv \left(1-\tilde{z}\right)\left(\kappa\omega-1\right)\left[\left(\kappa^3\omega^3-3\kappa\omega+2\right)\left(\kappa\omega+1\right)-2\left(\kappa^3\omega^3-1\right)\left(\kappa\omega-1\right)\right]. \tag{2.68}$$

It is immediate to show that $T_2 = -(1-\tilde{z})\kappa\omega(\kappa\omega-1)^4 < 0$. Furthermore, we can rewrite $T_1$ in the following way

$$T_1 = \tilde{z}\left(\kappa\omega-1\right)(\kappa-1)\omega\left[\left(\kappa^2+\kappa-2\right)\left(\kappa\omega+1\right)-4\frac{\left(\kappa\omega-1\right)\left(\kappa^2+\kappa+1\right)^2}{\kappa^2\omega+2\kappa\omega+12\omega-2\kappa-4}\right]$$

and, accounting for

$$\omega = 2\frac{\kappa^2+\kappa+1}{\kappa^2+\kappa+4}, \tag{2.69}$$

according to (2.50), we get

$$T_1 = -\tilde{z}\left(\kappa\omega-1\right)\omega\frac{(\kappa-1)^3\kappa(2\kappa+1)(\kappa^5+4\kappa^4+10\kappa^3+8\kappa^2+14\kappa+8)}{(\kappa^2+\kappa+4)(\kappa^4+2\kappa^3+12\kappa^2+8\kappa+4)} < 0.$$

Accounting for $T_1 < 0$ and $T_2 < 0$ we can thus conclude that $dY^c/d\hat{n} > 0$.

In a next step, we can now analyze the impact of an increase in $\hat{n}$ on $Y^u$. According to (2.60), we can calculate

$$\frac{dY^u}{d\hat{n}} = \frac{1}{4b}w^u\left(\frac{a}{w^u}-1\right)^2+\frac{1}{4b}\frac{dw^u}{dw^c}\frac{g(w^c)}{g'(w^c)}\left[\left(\frac{a}{w^u}\right)^2-1\right]. \tag{2.70}$$

Substituting $g(w^c)$ and $g'(w^c)$ from above and accounting for $\kappa = a/w^u$, we can show that $dY^u/d\hat{n} >,=,< 0$ is equivalent to

$$\begin{aligned} 0 >,=,< &\tilde{z}\omega(\kappa-1)\frac{dw^u}{dw^c}\left[\left(\kappa^2+\kappa-2\right)\left(\kappa+1\right)-2\left(\kappa^3-1\right)\right] \\ &+\left(1-\tilde{z}\right)\left[\frac{dw^u}{dw^c}\left(\kappa+1\right)\left(\kappa^3\omega^3-3\kappa\omega+2\right)-2\omega\left(\kappa-1\right)\left(\kappa^3\omega^3-1\right)\right] \end{aligned} \tag{2.71}$$

and thus equivalent to $0 >,=,< T_3 + T_4$, with

$$T_3 \equiv \tilde{z}\frac{dw^u}{dw^c}\omega\left(\kappa-1\right)\left[\left(\kappa^2+\kappa-2\right)\left(\kappa+1\right)-2\left(\kappa^3-1\right)\right] \tag{2.72}$$

$$T_4 \equiv \left(1-\tilde{z}\right)\left[\frac{dw^u}{dw^c}\left(\kappa+1\right)\left(\kappa^3\omega^3-3\kappa\omega+2\right)-2\omega\left(\kappa-1\right)\left(\kappa^3\omega^3-1\right)\right] \tag{2.73}$$

It is easily confirmed that $T_3 = -\tilde{z}\kappa\omega\left(\kappa-1\right)^3 dw^u/dw^c < 0$. Furthermore, substituting (2.66), we can rewrite $T_4$ in the following way

$$T_4 = 2(1-\tilde{z})\omega\left(\kappa\omega-1\right)\left[\frac{\left(\kappa^2+\kappa+1\right)\left(\kappa+1\right)\left(\kappa^2\omega^2+\kappa\omega-2\right)}{\kappa^2\omega+2\kappa\omega+12\omega-2\kappa-4} - \left(\kappa-1\right)\left(\kappa^2\omega^2+\kappa\omega+1\right)\right]$$

Rearranging terms and accounting for (2.69), we can simplify the latter to

$$\begin{aligned} T_4 = &-2(1-\tilde{z})\omega\left(\kappa\omega-1\right) \\ &\frac{\left(\kappa-1\right)^2\kappa\left(2\kappa^8+7\kappa^7+41\kappa^6+107\kappa^5+181\kappa^4+206\kappa^3+170\kappa^2+64\kappa+32\right)}{\left(\kappa^2+\kappa+4\right)^2\left(\kappa^4+2\kappa^3+12\kappa^2+8\kappa+4\right)}. \end{aligned}$$

which is unambiguously negative. In view of $T_3 < 0$ and $T_4 < 0$, we can thus conclude that $dY^u/d\hat{n} > 0$.

In a final step, we now investigate the impact of trade on the firm scale differential. To study this effect, we can note that

$$\Psi = Y^c - Y^u = \frac{\hat{n}}{4b}\left[w^c\left(\frac{a}{w^c}-1\right)^2 - w^u\left(\frac{a}{w^u}-1\right)^2\right] \tag{2.74}$$

Differentiating the latter, we obtain

$$\frac{d\Psi}{d\hat{n}} = \frac{1}{4b}\left[w^c\left(\frac{a}{w^c}-1\right)^2 - w^u\left(\frac{a}{w^u}-1\right)^2\right] + \frac{1}{4b}\frac{g(w^c)}{g'(w^c)}\left\{\left(\frac{a}{w^c}\right)^2 - 1 - \frac{dw^u}{dw^c}\left[\left(\frac{a}{w^u}\right)^2 - 1\right]\right\} \tag{2.75}$$

Substituting for $g(w^c)$ and $g'(w^c)$ from above and accounting for $\kappa = a/w^u$, we can conclude that $d\Psi/d\hat{n} >,=,< 0$ is equivalent to $0 >,=,< T5 + T6$, with

$$\begin{aligned} T_5 \equiv &\tilde{z}\omega(\kappa-1)\left\{\left(\kappa^2+\kappa-2\right)\left(\kappa^2\omega^2-1\right)\right. \\ &\left. -2\frac{\left(\kappa^2+\kappa+1\right)\left[\omega\left(\kappa^2+\kappa-2\right)\left(\kappa^2-1\right)+2\left(\kappa^2+\kappa+1\right)\left(\kappa^2\omega-1\right)\left(\omega-1\right)\right]}{\kappa^2\omega+2\kappa\omega+12\omega-2\kappa-4}\right\} \end{aligned} \tag{2.76}$$

and

$$\begin{aligned} T_6 \equiv &(1-\tilde{z})\left(\kappa\omega-1\right)\left\{\left(\kappa^2\omega^2+\kappa\omega-2\right)\left(\kappa^2\omega^2-1\right)-2\left(\kappa^2\omega^2+\kappa\omega+1\right)\left(\kappa^2\omega-1\right)\left(\omega-1\right)\right. \\ &\left. -2\omega\frac{\left(\kappa^2+\kappa+1\right)\left(\kappa^2\omega^2+\kappa\omega-2\right)\left(\kappa^2-1\right)}{\kappa^2\omega+2\kappa\omega+12\omega-2\kappa-4}\right\} \end{aligned} \tag{2.77}$$

respectively. Rearranging terms and accounting for (2.69), we can rewrite $T_5$ and $T_6$ in the following way:

$$\begin{aligned} T_5 &= -\tilde{z}\frac{\omega\kappa^2(\kappa+2)^2(\kappa-1)^4 t_5}{\left(\kappa^2+\kappa+4\right)^2\left(\kappa^4+2\kappa^3+12\kappa^2+8\kappa+4\right)} \\ T_6 &= -(1-\tilde{z})\frac{2\kappa^2\left(\kappa+2\right)^2\left(\kappa-1\right)^3\left(\kappa\omega-1\right)t_6}{\left(\kappa^2+\kappa+4\right)^4\left(\kappa^4+2\kappa^3+12\kappa^2+8\kappa+4\right)} \end{aligned}$$

with

$$t_5 \equiv 2\kappa^5 + 8\kappa^4 + 11\kappa^3 + 16\kappa^2 + 10\kappa + 16$$

and

$$t_6 \equiv 4\kappa^9 + 22\kappa^8 + 92\kappa^7 + 255\kappa^6 + 475\kappa^5 + 719\kappa^4 + 720\kappa^3 + 610\kappa^2 + 296\kappa + 128.$$

Since $t_5, t_6 > 0$, we have $T_5, T_6 < 0$ and thus $d\Psi/d\hat{n} > 0$, which confirms that the respective insight from the main text is not specific to the cost structure, we have chosen in the main text.

### 2.5.2 Extension – Firm level unions

Firm-level unions maximize objective function

$$\Omega_j = \frac{1}{4b(1-\rho)}\left[w_j^u - w^c\right] w_j^u \left[e^{\delta_j^u} - 1\right]^2 \tag{2.78}$$

instead of (2.10). Furthermore, when setting the wage, unions take wages in other firms as given, but at the same time account for the impact of their wage choice on scale and scope of the own firm in the output competition with the other producers. Since the union anticipates that a higher wage choice worsens the firm's position in the output competition, there exists an additional strategic effect if firm-level instead of sector-level unions are accounted for. For that reason, we have to solve for firm scale and scope as a function of the own and the competitors' wage before we can solve for the $\Omega$-maximizing $w_j$-level. Imposing the standard assumption that the union treats all other unions symmetrically, we can solve for firm scale of firm $j$ and $k \neq j$. Accounting for $Y = X_j^u + (n-1)X_k^u$ in (2.6) and adding over all varieties of $j$ and $k$, respectively, we obtain

$$X_j^u = \frac{\delta_j^u a - w_j^u\left(e^{\delta_j^u} - 1\right) - \delta_j^u (n-1) b\rho X_k^u}{2b(1-\rho) + 2\delta_j^u b\rho}, \quad X_k^u = \frac{\delta_k^u a - w_k^u\left(e^{\delta_k^u} - 1\right) - \delta_k^u b\rho X_j^u}{2b(1-\rho) + n\delta_k^u b\rho}. \tag{2.79}$$

In a similar vein, we can use (2.7) to calculate

$$e^{\delta_j^u} = \frac{a - 2b\rho X_j^u - (n-1)b\rho X_k^u}{w_j^u}, \quad e^{\delta_k^u} = \frac{a - nb\rho X_k^u - b\rho X_j^u}{w_k^u} \tag{2.80}$$

for the scope of firm $j$ and $k \neq j$, respectively. Rearranging terms the latter can be rewritten as

$$X_j^u = \frac{a - ne^{\delta_j^u} w_j + (n-1)e^{\delta_k^u} w_k^u}{b\rho(n+1)}, \quad X_k^u = \frac{a + e^{\delta_j^u} w_j^u - 2e^{\delta_k^u} w_k^u}{b\rho(n+1)}. \tag{2.81}$$

And substituting (2.81) into (2.79), we obtain a system of two equations, which implicitly determines $\delta_j^u$ and $\delta_k^u$ as functions of $w_j^u$ and $w_k^u$, respectively. To be more specific, we get

$$\begin{aligned}\Gamma_1(\delta_j^u, \delta_k^u; w_j^u, w_k^u) \equiv{}& 2a(1-\rho) - [\rho(n+1)]w_j^u + [3\rho n - 2n + \rho]w_j^u e^{\delta_j^u} \\ & - [\rho(n+1)]w_j^u \delta_j^u e^{\delta_j^u} + 2(1-\rho)(n-1)e^{\delta_k^u} w_k = 0, \end{aligned} \tag{2.82}$$

$$\begin{aligned}\Gamma_2(\delta_j^u, \delta_k^u; w_j^u, w_k^u) \equiv{}& 2a(1-\rho) - \rho(n+1)w_k^u + e^{\delta_k^u} w_k^u[\rho(n+1) - 4(1-\rho)] \\ & - \delta_k e^{\delta_k^u} w_k^u[\rho(n+1)] + 2(1-\rho)e^{\delta_j^u} w_j^u = 0. \end{aligned} \tag{2.83}$$

Differentiating system (2.82) and (2.83), and setting $dw_k = 0$, we obtain:

$$\frac{\partial \Gamma_1}{\partial w_j}dw_j + \frac{\partial \Gamma_1}{\partial \delta_j}d\delta_j + \frac{\partial \Gamma_1}{\partial \delta_k}d\delta_k + \frac{\partial \Gamma_1}{\partial w_k}dw_k = 0 \quad \Rightarrow \quad \frac{\partial \Gamma_1}{\partial \delta_j}\frac{d\delta_j}{dw_j} + \frac{\partial \Gamma_1}{\partial \delta_k}\frac{d\delta_k}{dw_j} = -\frac{\partial \Gamma_1}{\partial w_j} \quad \text{and}$$
$$\frac{\partial \Gamma_2}{\partial w_j}dw_j + \frac{\partial \Gamma_2}{\partial \delta_j}d\delta_j + \frac{\partial \Gamma_2}{\partial \delta_k}d\delta_k + \frac{\partial \Gamma_2}{\partial w_k}dw_k = 0 \quad \Rightarrow \quad \frac{\partial \Gamma_2}{\partial \delta_j}\frac{d\delta_j}{dw_j} + \frac{\partial \Gamma_2}{\partial \delta_k}\frac{d\delta_k}{dw_j} = -\frac{\partial \Gamma_2}{\partial w_j}.$$

Applying Cramer's rule, we obtain after tedious but straightforward calculations

$$\frac{d\delta_j^u}{dw_j^u} = \frac{[\rho(n+1)\delta_j^u e^{\delta_j^u} + \rho(n+1) - (3\rho n - 2n + \rho)e^{\delta_j^u}][4(\rho-1) - \rho(n+1)\delta_k^u] + [4(1-\rho)^2(n-1)e^{\delta_j^u}]}{w_j^u e^{\delta_j^u}[2n(\rho-1) - \rho(n+1)\delta_j^u][4(\rho-1) - \rho(n+1)\delta_k^u] - 4(1-\rho)^2(n-1)w_j^u e^{\delta_j^u}},$$

which we need for determining the $\Omega_j$-maximizing wage rate. The latter is characterized by the first-order condition

$$\frac{d\Omega_j}{dw_j^u} = \frac{e^{\delta_j^u} - 1}{4b(1-\rho)}\left[\left(2w_j^u - w^c\right)\left(e^{\delta_j^u} - 1\right) + 2\left(w_j^u - w^c\right)w_j^u e^{\delta_j^u}\frac{d\delta_j^u}{dw_j^u}\right] = 0. \tag{2.84}$$

Substituting for $d\delta_j^u/dw_j^u$ and, in view of our symmetry assumption, setting $w_j^u = w_k^u$, we can calculate

$$w^u = w^c\left[1 - \frac{1}{2}\frac{\left[e^{\delta^u} - 1\right]}{e^{\delta^u} - 1 + G(\delta^u)}\right], \tag{2.85}$$

with $G(\delta^u) \equiv w_j^u e^{\delta_j^u} \times d\delta_j^u/dw_j^u$. Setting $\rho = 0$, gives $G(\delta^u) = -e^{\delta^u}$ and thus

$$w^u = \frac{w^c}{2}\left[e^{\delta^u} + 1\right], \tag{2.86}$$

according to (2.85). Accounting for $e^{\delta^u} = a/w^u$, according to (2.7), it is then immediate that in the benchmark model with $\rho = 0$, firm-level unions set the same wage as sector-level unions (see (2.11)) and, hence, there is no difference between the two settings in this special case. This result is intuitive as $\rho = 0$ implies perfect product differentiation, so that firms act as monopolists in any of their submarkets. However, facing a monopolist, the level of centralization in union wage setting (firm-level vs. sector-level) becomes irrelevant. In the more general case with $\rho > 0$, the autarky equilibrium values of $w^c, w^u, \delta^c, \delta^u$, and $X^c, X^u$ are implicitly given by (2.7) – separately for $u$ and $c$ –, (2.12), (2.85), and, setting $\delta_j = \delta_k$ in (2.81),[27]

$$X^u = \frac{a - e^{\delta^u}w^u}{b\rho(n+1)}, \quad X^c = \frac{a - e^{\delta^c}w^c}{b\rho(n+1)}. \tag{2.87}$$

Having solved for these variables, we can easily calculate $\omega$, $\Delta$, and $\Psi$ as well as the total number of available product varieties $N$.

Similar to the main text, we can now analyze the comparative-static effects of deunionization on the main variables of interest. However, since the firm-level union scenario turns out to be much more complicated than the sector-level union scenario from the main text, we cannot rely on analytical tools but instead have to conduct numerical simulation experiments in order to gain insights into the respective effects. The following table summarizes the main insights from these experiments.

[27]Notably, (2.87) can also be inferred from (2.8), when substituting $e^{\delta_j(z)}(\delta_j(z) - 1) + 1 = \left[a/w(z) - e^{\delta_j(z)}\right]/\phi$, according to (2.9).

| | $w^c$ | $w^u$ | $\delta^c$ | $\delta^u$ | $X^c$ | $X^u$ | $\omega$ | $\Delta$ | $\Xi$ | $N$ |
|---|---|---|---|---|---|---|---|---|---|---|
| $\widetilde{z} = 0.1$ | 66.57 | 75.16 | 0.202 | 0.156 | 3.87 | 2.53 | 1.13 | 0.047 | 1.34 | 0.9848 |
| $\widetilde{z} = 0.3$ | 64.82 | 73.76 | 0.211 | 0.163 | 4.16 | 2.74 | 1.14 | 0.048 | 1.42 | 0.9834 |
| $\widetilde{z} = 0.5$ | 62.87 | 72.20 | 0.221 | 0.171 | 4.48 | 2.98 | 1.15 | 0.050 | 1.51 | 0.9830 |

Parameter values are $a = 100$, $b = 1$, $\rho = 0.8$, $n = 5$, $L = 20$.

Table 2.2: Autarky equilibrium variables for different levels of $\tilde{z}$ with firm-level unions

The results in Table 2.2 indicate that the main results regarding the impact of deunionization on multi-product firms extend to the case of firm-level unions. Deunionization increases labor demand and thus provides a stimulus for the wage rate in unionized and non-unionized industries. This wage increase render the shortening of the product range attractive and thus induce a decline in $\delta^c$ and $\delta^u$. Total firm scale declines in all industries except of the newly deunionized ones. Regarding the impact of deunionization on relative firm performance, we see from Table 2.2 that the union wage premium falls in response to deunionization and this effect is instrumental for a decline in the scale and scope differential between non-unionized and unionized firms. Finally, while the figures in Table 2.2 suggest a positive impact of deunionization on the total number of available varieties, we are able to show that the respective impact is non-monotonic. For sufficiently high levels of $\tilde{z}$, (marginal) deunionization exerts a negative impact on $N$.[28]

In a final step, we now look at the open economy. Following the analysis from the closed economy, it is easily confirmed that the open economy equilibrium is characterized by (2.41) – again separately for $u$ and $c$ –, (2.46), (2.85), and

$$X_t^u = 2\frac{a - e^{\delta^u} w^u}{b\rho(n+1)}, \quad X_t^c = 2\frac{a - e^{\delta^c} w^c}{b\rho(n+1)}, \tag{2.88}$$

where subscript $t$ refers to trade. Similar to the model variant with sector-level unions, trade provides a labor demand stimulus and thus raises $w^c$. Regarding the unionized wage there is a counteracting effect, as trade lowers the unions scope for setting excess wages. While with sector-level unions the latter effect may be strong enough to induce an overall fall of union wages in response to trade liberalization, there is a presumption from previous work on SPF that such an outcome is not possible if unions are organized at the firm level (see Bastos and Kreickemeier, 2009). The results from our numerical simulation exercise provide support for this difference and indicate that union wages increase along with the competitive wage in response to a country's movement from autarky to free trade with a symmetric partner country if unions are organized at the firm level (see Table 2.3). The wage increase triggers a fall in firm scope in all industries, while output increases in unionized but not necessarily in non-unionized industries. Finally, the impact of trade on the relative performance of unionized and non-unionized firms remains the same as in the model variant with sector-level unions. This can be confirmed by comparing the figures in Tables 2.1 and 2.3.

[28] The $N$-levels for $\tilde{z} = 0.99$, $\tilde{z} = 0.95$ and $\tilde{z} = 0.9$ are 0.985671, 0.985287, and 0.98484, respectively.

| | $w_t^u - w_a^u$ | $w_t^c - w_a^c$ | $\delta_t^u - \delta_a^u$ | $\delta_t^c - \delta_a^c$ | $D_t^u - D_a^u$ | $D_t^c - D_a^c$ | $X_t^u - X_a^u$ | $X_t^c - X_a^c$ |
|---|---|---|---|---|---|---|---|---|
| $\widetilde{z} = 0.1$ | 2.68 | 5.3 | -0.04 | -0.06 | -1.11 | -1.91 | 0.32 | 0.05 |
| $\widetilde{z} = 0.3$ | 3.04 | 5.83 | -0.04 | -0.07 | -1.22 | -2.08 | 0.29 | -0.01 |
| $\widetilde{z} = 0.5$ | 3.48 | 6.47 | -0.05 | -0.07 | -1.36 | -2.29 | 0.25 | -0.09 |

Notes: $D$ denotes domestic firm-level output and subscripts $a$, $t$ refer to autarky and trade variables, respectively. Parameter values are $a = 100$, $b = 1$, $\rho = 0.8$, $n = 5$, $L = 20$.

Table 2.3: Trade effects on wages, scope and scale for different degrees of unionization and firm-level unions

### 2.5.3 Program codes for simulation exercises

All simulation exercises has been executed in *Mathematica*.

#### Program code for Table 2.1

In the following we offer the source code to derive the reported values from Table 2.1. At first, we set the parameter values: $a = 100$, $b = 1$, $\rho = 0.8$, $n = 5$, $L = 20$, which determines $\phi = \rho(n+1)/[2(1-\rho)]$ and set the share of unionized industry equal to $\tilde{z} = 0.1$, $\tilde{z} = 0.3$ or $\tilde{z} = 0.5$.[29]

```
a=100;
b=1;
ρ=0.8;
n=5;
L=20;
ϕ=(ρ(n+1))/(2(1-ρ));
z=0.1; (* z=0.3 ; z=0.5 *)
```

In a next step we use Equations (2.9), (2.11) and (2.12) to define

```
g1=0.5*wc+a(1-wc/wu)/((Exp[δu]-1)(1+ϕδu));
g2=Log[((a/wu)-ϕ)/(1+ϕδu-ϕ)];
g3=Log[((a/wc)-ϕ)/(1+ϕδc-ϕ)];
g4=(4*b(1-ρ)L/n-z*wu(Exp[δu]-1)^2)/((1-z)(Exp[δc]-1)^2);
```

where wu denotes the union wage, wc the competitive wage, $\delta u$ firm scope in unionized and $\delta c$ in non-unionized sectors. To solve the autarky situation, we use the FindRoot command and print the variables of interest:

```
B=FindRoot[{wu==g1,δu==g2,δc==g3,wc==g4},{wc, 75},{wu, 89},{δc, 0.15},{δu,
0.1}];
Print["Union wage autarky:  ", wu1=g1/.B];
Print["Scope unionized autarky:  ", δu1=g2/.B];
Print["Scope non-unionized autarky:  ", δc1=g3/.B];
Print["Competitive wage rate autarky:  ", wc1=g4/.B];
```

[29] In the source code, we use $z$ instead $\tilde{z}$ to save on notation.

```
Print["Scale unionized autarky:  ", Du=(wu1(Exp[δu1](δu1-1)+1))/(2b(1-ρ))];
Print["Scale non-unionized autarky:  ", Dc=(wc1(Exp[δc1](δc1-1)+1))/(2b(1-ρ))];
```

In a next step we use Equations (2.44), (2.41) and (2.46) from the open economy to define

```
Hδut=

((ϕ+(1+ϕ*δut-ϕ)Exp[δut])(1+ϕ*δut)-((ρ*n)^2*δut(Exp[δut](δut-1)+1))/(4(1-ρ)^2))/
        ((1+ϕδut)^2-((ρ*n)^2*δut^2)/(4(1-ρ)^2));
g10=wct(1+(0.5(Exp[δut]-1))/(1-Exp[δut]+Hδut));
g20=Log[(a/wut-ϕ((2n+1)/(n+1)))/(1+((2n+1)/(n+1))(ϕ*δut-ϕ))];
g30=Log[(a/wct-ϕ((2n+1)/(n+1)))/(1+((2n+1)/(n+1))(ϕ*δct-ϕ))];
g40=(2*b(1-ρ)L/n-z*wut(Exp[δut]-1)^2)/((1-z)(Exp[δct]-1)^2);
```

where the letter $t$ added to wu, wc, $\delta u$ and $\delta c$ refers to trade. To solve the open economy situation, we use the FindRoot command and print the variables of interest:

```
B=FindRoot[{wut==g10,δut==g20,δct==g30,wct==g40},{wct, 75},{wut, 89},{δct,
0.15},{δut, 0.1}];
Print["Union wage trade:  ", wut1=g10/.B];
Print["Scope unionized trade:  ", δut1=g20/.B];
Print["Scope non-unionized trade:  ", δct1=g30/.B];
Print["Competitive wage rate trade:  ", wct1=g40/.B];
Print["Scale home unionized trade:  ",
Dut=(wut1(Exp[δut1](δut1-1)+1))/(2*b(1-ρ))];
Print["Scale home non-unionized trade:  ",
Dct=(wct1(Exp[δct1](δct1-1)+1))/(2*b(1-ρ))];
Print["Scale unionized trade:  ", Xut=(wut1(Exp[δut1](δut1-1)+1))/(b(1-ρ))];
Print["Scale non-unionized trade:  ",
Xct=(wct1(Exp[δct1](δct1-1)+1))/(b(1-ρ))];
```

Finally, we compare the free trade with the closed economy variables, to derive the values as reported in Table 2.1.

```
Print["Impact on union wage:  ", Round[wut1-wu1,0.01]];
Print["Impact on competitive wage:  ", Round[wct1-wc1,0.01]];
Print["Impact on scope unionized:  ", Round[δut1-δu1,0.01]];
Print["Impact on scope non-unionized:  ", Round[δct1-δc1,0.01]];
Print["Impact on scale home unionized:  ", Round[Dut-Du,0.01]];
Print["Impact on scale home non-unionized:  ", Round[Dct-Dc1,0.01]];
Print["Impact on scale unionized:  ", Round[Xut-Du,0.01]];
Print["Impact on scale non-unionized:  ", Round[Xct-Dc,0.01]];
```

### Program code for Table 2.2

In the following we offer the source code to derive the reported values from Table 2.2. At first, we set the parameter values: $a = 100$, $b = 1$, $\rho = 0.8$, $n = 5$, $L = 20$, which determines $\phi = \rho(n + 1)/[2(1 - \rho)]$ and set the share of unionized industry equal to $\tilde{z} = 0.1$, $\tilde{z} = 0.3$ or $\tilde{z} = 0.5$.

```
Clear["Global`*"];
```

```
a=100;
b=1;
ρ=0.8;
n=5;
L=20;
ϕ=(ρ(n+1))/(2(1-ρ));
z=0.1; (* z=0.3 ; z=0.5 *)
```

In a next step we use Equations (2.9), (2.85) and (2.12) to define

```
Gδu=
(((ρ(n+1))(Exp[δu]δu+1)-(3*ρ*n-2*ρ*n)Exp[δu])(4(ρ-1)-ρ(n+1)δu)+
4(1-ρ)^2(n-1)Exp[δu])/ ((2*n(ρ-1)-ρ(n+1)δu)(4(ρ-1)-(ρ(n+1)δu))-4(1-ρ)^2(n-1));
g1=wc(1-0.5(Exp[δu]-1)/(Exp[δu]-1+Gδu));
g2=Log[(a/wu-ϕ)/(1+ϕδu-ϕ)];
g3=Log[(a/wc-ϕ)/(1+ϕδc-ϕ)];
g4=(4*b(1-ρ)L/n-z*wu(Exp[δu]-1)^2)/((1-z)(Exp[δc]-1)^2);
```

To solve the autarky situation, we use the FindRoot command and print the variables of interest, that are listed in Table 2.2:

```
B=FindRoot[{wu==g1,δu==g2,δc==g3,wc==g4},{wc, 40},{wu, 50},{δc, 0.15},{δu,
0.1}];
Print["Competitive wage:  ", wc1=g4/.B];
Print["Union wage:  ", wu1=g1/.B];
Print["Scope non-unionized:  ", δc1=g3/.B];
Print["Scope unionized:  ", δu1=g2/.B];
Print["Scale non-unionized:  ", Xc=(wc1(Exp[δc1](δc1-1)+1))/(2*b(1-ρ))];
Print["Scale unionized:  ", Xu=(wu1(Exp[δu1](δu1-1)+1))/(2*b(1-ρ))];
Print["Union wage premium:  ", ω=wu1/wc1];
Print["Scope Differential:  ", Δ=δc1-δu1];
Print["Scale Differential:  ", Ξ=Xc-Xu];
Print["Number of varieties:  ", Nt=z*n*δu1+(1-z)n*δc1];
```

**Program code for Table 2.3**

In the following we offer the source code to derive the reported values from Table 2.3. At first, we set the parameter values: $a = 100$, $b = 1$, $\rho = 0.8$, $n = 5$, $L = 20$, which determines $\phi = \rho(n+1)/[2(1-\rho)]$ and set the share of unionized industry equal to $\tilde{z} = 0.1$, $\tilde{z} = 0.3$ or $\tilde{z} = 0.5$.

```
Clear["Global‘*"];
a=100;
b=1;
ρ=0.8;
n=5;
L=20;
ϕ=(ρ(n+1))/(2(1-ρ));
z=0.1; (* z=0.3 ; z=0.5 *)
```

In a next step we use Equations (2.9), (2.85) and (2.12) to define

```
Gδu=
(((ρ(n+1))(Exp[δu]δu+1)-(3*ρ*n-2*ρ*n)Exp[δu])(4(ρ-1)-ρ(n+1)δu)+
4(1-ρ)^2(n-1)Exp[δu])/ ((2*n(ρ-1)-ρ(n+1)δu)(4(ρ-1)-(ρ(n+1)δu))-4(1-ρ)^2(n-1));
g1=wc(1-0.5(Exp[δu]-1)/(Exp[δu]-1+Gδu));
g2=Log[(a/wu-ϕ)/(1+ϕδu-ϕ)];
g3=Log[(a/wc-ϕ)/(1+ϕδc-ϕ)];
g4=(4*b(1-ρ)L/n-z*wu(Exp[δu]-1)^2)/((1-z)(Exp[δc]-1)^2);
```

To solve the autarky situation, we use the FindRoot command and print the variables of interest:

```
B=FindRoot[{wu==g1,δu==g2,δc==g3,wc==g4},{wc, 40},{wu, 50},{δc, 0.15},{δu,
0.1}];
Print["Union wage autarky:  ", wu1=g1/.B];
Print["Scope unionized:  ", δu1=g2/.B];
Print["Scope non-unionized:  ", δc1=g3/.B];
Print["Competitive wage autarky:  ", wc1=g4/.B];
Print["Scale unionized autarky:  ", Du=(wu1(Exp[δu1](δu1-1)+1))/(2*b(1-ρ))];
Print["Scale non-unionized autarky:  ",
Dc=(wc1(Exp[δc1](δc1-1)+1))/(2*b(1-ρ))];
```

In a next step we use Equations (2.41), (2.46) and (2.85) to define

```
Gδut=
(((ρ(2n+1))(Exp[δut]δut+1)-(6*ρ*n-4*ρ*n)Exp[δut])(4(ρ-1)-ρ(2*n+1)δut)
        +4(1-ρ)^2(2*n-1)Exp[δut])/
((4*n(ρ-1)-ρ(2*n+1)δut)(4(ρ-1)-(ρ(2*n+1)δut))-4(1-ρ)^2(2*n-1));
g10=wct(1-0.5(Exp[δut]-1))/(Exp[δut]-1+Gδut);
g20=Log[(a/wut-ϕ((2*n+1)/(n+1)))/(1+((2n+1)/(n+1))ϕδut-ϕ)];
g30=Log[(a/wct-ϕ((2*n+1)/(n+1)))/(1+((2n+1)/(n+1))ϕδct-ϕ)];
g40=(2*b(1-ρ)L/n-z*wut(Exp[δut]-1)^2)/((1-z)(Exp[δct]-1)^2);
```

To solve the open economy situation, we use the FindRoot command and print the variables of interest:

```
B=FindRoot[{wut==g10,δut==g20,δct==g30,wct==g40},{wct, 40},{wut, 50},{δct,
0.15},{δut, 0.1}];
Print["Union wage trade:  ", wut1=g10/.B];
Print["Scope unionized trade:  ", δut1=g20/.B];
Print["Scope non-unionized trade:  ", δct1=g30/.B];
Print["Competitive wage rate trade:  ", wct1=g40/.B];
Print["Scale home unionized trade:  ",
Dut=(wut1(Exp[δut1](δut1-1)+1))/(2*b(1-ρ))];
Print["Scale home non-unionized trade:  ",
Dct=(wct1(Exp[δct1](δct1-1)+1))/(2*b(1-ρ))];
Print["Scale unionized trade:  ", Xut=(wut1(Exp[δut1](δut1-1)+1))/(b(1-ρ))];
Print["Scale non-unionized trade:  ",
Xct=(wct1(Exp[δct1](δct1-1)+1))/(b(1-ρ))];
```

Finally, we compare the free trade with the closed economy variables, to derive the values as reported in Table 2.1.

```
Print["Impact on union wage:  ", Round[wut1-wu1,0.01]];
Print["Impact on competitive wage:  ", Round[wct1-wc1,0.01]];
Print["Impact on scope unionized:  ", Round[δut1-δu1,0.01]];
Print["Impact on scope non-unionized:  ", Round[δct1-δc1,0.01]];
Print["Impact on scale home unionized:  ", Round[Dut-Du,0.01]];
Print["Impact on scale home non-unionized:  ", Round[Dct-Dc1,0.01]];
Print["Impact on scale unionized:  ", Round[Xut-Du,0.01]];
Print["Impact on scale non-unionized:  ", Round[Xct-Dc,0.01]];
```

# Chapter 3

# Trade and the Firm-Internal Allocation of Workers to Tasks

## 3.1 Introduction

In any industrialized economy, labor markets have to solve the complex problem of matching task-specific skill requirements and worker-specific abilities. The outcome of this matching process is typically not efficient. This is not only because some workers do not find a job at all. Rather, a significant share of workers cannot exploit full productivity because they are not matched with the best occupation (see Legros and Newman, 2002; Eeckhout and Kircher, 2011). In recent years, this source of inefficiency has also sparked considerable attention in the trade literature. With an increasing general interest in the consequences of trade for *underemployment*, several authors have highlighted improvements in matching quality as a key aspect of gains from trade in terms of both welfare and employment (Amiti and Pissarides, 2005; Davidson, Matusz, and Shevchenko, 2008; Larch and Lechthaler, 2011). Thereby, the typical approach is to associate the quality of the matching process with its ability to match heterogeneous workers with heterogeneous firms in an efficient way, assuming implicitly that the production process covers just a single task with a certain skill requirement. However, this ignores the sophisticated structure of modern production processes and thus misses an important role of firms in reducing the requirement-ability mismatch by improving the assignment of workers to specific tasks within the boundaries of a single production entity.[1]

Studying the role of firms for matching workers with tasks and discussing how access to trade affects the matching outcome is the main purpose of this chapter. Starting point of our analysis is a Melitz (2003) model, in which firms are heterogeneous due to differences in their productivity levels. As in Acemoglu and Autor (2011), we assume that production consists of a continuum of tasks that differ in their skill requirements. For performing these tasks, firms hire heterogeneous workers. Heterogeneity is horizontal in the sense that workers differ in their ability to perform specific tasks because their human capital is occupation-specific (see

[1]The idea that the quality of worker-task matches are important for firm performance at least dates back to work by Barron and Loewenstein (1985) and Barron, Black, and Loewenstein (1989). Meyer (1994) points to the relevance of optimal task assignment in the context of team production. Burgess, Propper, Ratto, von Hinke Kessler Scholder, and Tominey (2010) show that productivity losses from a mismatch of workers and tasks in teams can indeed be significant and that one important channel through which incentive payments to managers can improve the outcome of production units is the better assignment of workers to tasks.

Kambourov and Manovskii, 2009; Sullivan, 2010, for empirical evidence), while they are equally productive over the whole range of activities. This implies that all workers have the same value to firms and, lacking information about abilities of individual workers, firms randomly draw their employees from the labor supply pool. This lack of information generates a source of mismatch between task-specific skill requirements and worker-specific abilities within the boundaries of a production unit. To reduce this mismatch, firms can invest into a screening technology for gathering some (imperfect) information about the abilities of their workforce. We model the screening investment in a rudimentary way, allowing for two possible interpretations that are common in the literature. On the one hand, screening may be part of the recruitment process as in Helpman, Itskhoki, and Redding (2010) and can help narrowing the pool of suitable applicants. On the other hand, screening may take place after the recruitment of workers, for instance, in the form of job rotation (see Li and Tian, 2013).[2] In both interpretations, a higher investment provides better knowledge about the abilities of workers and therefore leads to a better match of these workers with the different tasks in the production process (cf. Pellizzari, 2011). The incentives to screen are more pronounced in larger firms, and hence there is an additional source of heterogeneity in our model, which is endogenous and reinforces heterogeneity of firms due to exogenous differences in firm productivity.

We use this model to shed new light on the consequences of trade for labor market outcome, thereby focussing on adjustments in the firm-internal labor market.[3] To be more specific, we are interested in how trade affects underemployment arising from a mismatch between worker-specific abilities and task-specific skill requirements. To keep the analysis simple, we focus on trade between symmetric countries and consider the empirically relevant case, in which only the most productive firms export in the open economy (see, for instance, Bernard and Jensen, 1995, 1999). Having access to the export market, high-productivity firms can expand their market share in the open economy, which provides an incentive for these firms to screen their workforce more intensively, as this further improves the matching quality and thus lowers production costs. Low-productivity non-exporters, on the other hand, lose market share and thus lower their investment into the screening technology, which raises their production costs. By changing the cost structure, this asymmetric response to trade liberalization exerts a feedback effect on the entry/exit decision of firms in both the domestic and the export market, which is not present in other trade models with heterogeneous firms. Furthermore, it alters the productivity distribution of active firms by driving a wedge between matching efficiency of exporters and non-exporters. This provides an alternative to the 'learning-by-exporting' hypothesis for explaining the empirical finding that firms become more productive when entering the export market (see Fryges and Wagner, 2008).[4] Finally, adjustments in the firm-internal labor allocation process lower the *aggregate* mismatch between worker-specific abilities and task-specific skill requirements, thereby generating a productivity stimulus that reinforces the gains from trade in an otherwise identical Melitz (2003) model. The firm-level adjustments to trade liberalization

[2]The literature distinguishes three motives for job rotation: *employee learning* (job rotation as a training device); *employee motivation* (job rotation makes work more interesting) and *employer learning* (job rotation as a way to discover in which jobs different employees are best at). Our model is in line with the 'employer learning' view, which was first discussed by Ortega (2001). Empirical support for this motive is provided by Eriksson and Ortega (2006).

[3]According to Doeringer and Piore (1971) an *internal labor market* is "an administrative unit, such as a manufacturing plant, within which the pricing and allocation of labor is governed by a set of administrative rules and procedures. [... This market] is to be distinguished from the *external labor market* of conventional economic theory where pricing, allocating and training decisions are controlled directly by economic variables" (pp. 1f).

[4]Greenaway and Kneller (2007) and Wagner (2007) summarize existing empirical evidence regarding the feedback effects of exporting on firm productivity. Our reading of the literature is that there is some support for such a positive feedback effect, but not all existing studies can identify a significant impact.

are not so different, in principle, from the adjustments in Helpman, Itskhoki, and Redding (2010). In their model, firms can invest into a screening technology in order to receive a more precise signal about the quality of applicants. More specifically, screening allows the firm to detect (and reject) applicants below a certain ability threshold. The higher the investment, the more effective is screening and the higher is the average ability of workers employed by the firm. The screening investment is endogenous and responds to trade in a similar way as the screening investment does in our model. It increases in exporting firms and shrinks in non-exporting ones. Aside from these similarities, there is a crucial difference between the focus of Helpman, Itskhoki, and Redding (2010) and the focus of this chapter. Whereas Helpman, Itskhoki, and Redding (2010) study imperfections in the external labor market, we are interested in the firm-internal allocation of workers. To be more explicit, in our setting all workers are equally valuable to firms and only differ in their ability to perform specific tasks, whereas workers in Helpman, Itskhoki, and Redding (2010) differ in the productivity they can elicit in a firm of a specific type. Hence, there is an efficiency loss in the Helpman, Itskhoki, and Redding (2010) model, because firms are not matched with the *ideal* worker, while there is an efficiency loss in our setting, because workers do not perfectly fit the skill requirements of tasks they are performing within the boundaries of a firm.

By opening up the black box of production and modeling explicitly the firm-internal labor allocation process, our model not only identifies a new channel through which positive trade effects can materialize, but also contributes to a growing literature on the role of globalization for firm organization. A first line of research in this literature has pointed to the role of openness for the boundaries of firms (see Grossman and Helpman, 2002; Antrás, 2003; Antrás and Helpman, 2004; Conconi, Legros, and Newman, 2012). In contrast to these studies, we focus on the question how trade changes the organization of labor within these boundaries. This renders our analysis akin to Marin and Verdier (2008a, 2012) who investigate the impact of trade on the hierarchy structure in firms and the incentives to empower human capital. The hierarchy structure of firms is also addressed by Caliendo and Rossi-Hansberg (2012) who analyze how access to exporting changes the number of layers of management.[5] In contrast to all of these studies, we do not look on changes in the hierarchy structure but on matching quality, so that our findings are complementary to the results in this literature. Finally, the key mechanism discussed in this chapter differs from a pure division of labor effect, which arises if there is a change in the number of tasks performed by a single worker (Becker and Murphy, 1992) or a team of workers (Chaney and Ossa, 2013). In our setting, it is not the number of tasks performed by a single worker but rather the matching of workers with these tasks that matters.

The remainder of the chapter is organized as follows. In Chapter 3.2, we set up a baseline model with a perfect labor market and characterize the equilibrium in the closed economy. In Chapter 3.3, we consider trade between two symmetric countries, characterize the open economy equilibrium, and investigate how a movement from autarky to trade affects the allocation of labor 'inside' the firm as well as per capita income. We also shed light on the consequences of marginal trade liberalization. In Chapter 3.4, we extend the baseline model to one with search frictions in the hiring process and analyze how imperfections in the outside labor market alter our insights regarding the impact of trade on the firm-internal organization of workers. Chapter 3.5 provides a calibration exercise that allows us to quantify the impact of trade on welfare and underemployment. Chapter 3.6 concludes with a brief summary of the most important results.

[5] In a recent study, Sly (2012) investigates the composition of management teams and shows that trade can alter this composition significantly.

## 3.2 The closed economy

### 3.2.1 Model structure

We consider an economy that is populated by an exogenous mass of workers $L$, who supply one unit of labor in a perfectly competitive labor market. There are two sectors of production: a perfectly competitive final goods industry that produces a homogeneous output good by assembling differentiated intermediate goods; and a monopolistically competitive intermediate goods industry that hires labor for its production of differentiated goods. Similar to Egger and Kreickemeier (2009, 2012), we represent the final goods technology by a constant-elasticity-of-substitution (CES) production function without external scale economies. To be more specific, we assume that the technology for producing final output $Y$ is given by

$$Y = \left[ M^{-\frac{1}{\sigma}} \int_{\omega \in \Omega} x(\omega)^{\frac{\sigma-1}{\sigma}} d\omega \right]^{\frac{\sigma}{\sigma-1}}, \tag{3.1}$$

where $x(\omega)$ denotes the quantity of intermediate good $\omega$ used in the final goods production, $M$ is the Lebesgue measure of set $\Omega$ and represents the mass of available intermediate goods, and $\sigma > 1$ denotes the (constant) elasticity of substitution between different product varieties. $Y$ serves as numéraire in our analysis, implying that the price index corresponding to the production function in Eq. (3.1) is equal to one, by assumption. Denoting by $p(\omega)$ the price of intermediate good $\omega$, we can write total costs of producing output $Y$ as follows: $\int_{\omega \in \Omega} p(\omega) x(\omega) d\omega$. Maximizing final goods profits with respect to $x(\omega)$, then gives intermediate goods demand

$$x(\omega) = \frac{Y}{M} p(\omega)^{-\sigma}. \tag{3.2}$$

At the intermediate goods level, there is a continuum of firms, each of them supplying a unique variety under monopolistic competition. Following Acemoglu and Autor (2011), we assume that intermediate goods production is a composite of different tasks. To be more specific, there is a continuum of tasks that is represented by the unit interval. The production technology is of the Cobb-Douglas type and given by

$$x(\omega) = \phi(\omega) \exp \left[ \int_0^1 \ln x(\omega, i) di \right], \tag{3.3}$$

where $x(\omega, i)$ is the production level of task $i$ in firm $\omega$ and $\phi(\omega)$ is this firm's *baseline* productivity. Task $x(\omega, i)$ is performed (produced) by workers who are employed in a linear-homogenous production technology, which is the same for all tasks. To keep things simple, we assume that task-level output is equal to the effective labor input: the mass of workers performing the task multiplied by these workers' average productivity. The productivity of workers in performing a specific task differs, because workers differ in their abilities, whereas tasks differ in their skill requirements. To capture this in a tractable way, we assume that both workers and tasks are uniformly distributed along the unit interval, and the gap between ability and skill requirement is measured by the distance of a worker to the task in the unit interval.

In the hiring process firms have to solve the problem of matching specific workers with specific tasks, and this is essential because firms face an efficiency loss from mismatch if workers do not end up in those occupations, in which they have the highest competence. The degree of mismatch depends on the *average* distance between workers and tasks in a firm's production process. To determine this average distance, we can first note that the expected distance when randomly assigning workers from interval $[0, b]$ to a task located at $t \in [0, b]$ is given by

$$dist(t) = \frac{1}{b}\left[\int_0^t (t-j)dj + \int_t^b (j-t)dj\right] = \frac{1}{b}\left(t^2 - tb + \frac{b^2}{2}\right), \tag{3.4}$$

where $j$ gives the location of workers in the considered interval. Accordingly, the expected distance when drawing $t$ randomly from interval $[0, b]$ amounts to

$$\widehat{dist} = \frac{1}{b^2}\int_0^b \left(t^2 - tb + \frac{b^2}{2}\right) dt = \frac{b}{3}. \tag{3.5}$$

From (3.5) it follows that the extent of mismatch crucially depends on the length of the interval, $b$. We interpret $b$ as the amount of information firms have about the location of workers in the unit interval. Without screening, firms are uninformed about the specific abilities of their applicants. Hence, they hire workers by randomly selecting them from the labor supply pool at the common market-clearing wage rate $w$.[6] This gives $b = 1$ and $\widehat{dist} = 1/3$.

However, firms do not have to accept this outcome. They can reduce the efficiency loss from mismatch by screening their applicants. Similar to Helpman, Itskhoki, and Redding (2010), we associate the implementation of a screening technology with a fixed cost expenditure $f_\mu = [1+\mu(\omega)]^\gamma$ and assume that screening provides an imprecise signal about worker ability, with the quality of the signal increasing in screening effort $\mu(\omega)$. To be more specific, by screening with effort $\mu(\omega)$, a firm can divide the ability interval into $1+\mu(\omega)$ segments of equal length. Firms can then hire workers at the market-clearing wage rate, $w$, for a specific task by randomly selecting them from the respective ability segment, so that the average distance between worker-specific abilities and task-specific skill requirements reduces to $\widehat{dist}(\omega) = (1/3)\,[1+\mu(\omega)]^{-1}$.[7]

At the firm level, efficiency of workers in the performance of tasks is inversely related to $\widehat{dist}(\omega)$ and denoted by $\kappa(\omega)$. In the interest of analytical tractability, we choose a specific functional form and capture the relationship between $\kappa(\omega)$ and $\widehat{dist}(\omega)$ by $\kappa(\omega) \equiv (1/3)\widehat{dist}(\omega)^{-1}$. This gives $\kappa(\omega) = 1 + \mu(\omega)$. Effective labor input at the task level is therefore given by $[1 + \mu(\omega)]l(\omega)$ and, since tasks enter production function (3.3) symmetrically, total output of firm $\omega$ can be written in the following way:

$$x(\omega) = \phi(\omega)\,[1 + \mu(\omega)]\,l(\omega). \tag{3.6}$$

According to (3.6), firm productivity consists of two parts: an exogenous baseline productivity $\phi(\omega)$, which captures the efficiency of coordinating the bundle of different tasks within the boundaries of the firm, and an endogenous productivity term $\kappa(\omega) = 1 + \mu(\omega)$, which captures how effectively the heterogeneous abilities of workers are used for performing the different tasks in the production process. Crucially, firms can increase their productivity by investing into a screening technology which improves the matching quality in the firm-internal labor allocation process and thus raises $\kappa(\omega)$.[8]

The baseline productivity is drawn by firms in a lottery from the common Pareto distribution, $G(\phi) = 1 - \phi^{-\nu}$. To participate in this lottery, firms have to pay a fee $f_e$ in units of final output $Y$. This investment allows just a single draw and is immediately sunk. After productivity levels

[6] Due to symmetry, all workers receive the same wage in equilibrium, irrespective of their location in the ability interval.

[7] We ignore integer problems and, due to symmetry, suppress task indices.

[8] This mechanism is not too different, in principle, from an *R&D* investment that lowers variable production costs (see, for instance, Eckel, 2009).

are revealed, producers decide upon setting up a plant and starting production. This involves an additional fixed cost $f$ (in units of final output) for setting up a local distribution network. Only firms with a sufficiently high baseline productivity will pay this additional fixed cost and start production, while firms with a low $\phi$ will stay out of the market. This two-stage entry mechanism is similar to Melitz (2003), with two main differences. On the one hand, we consider a static model variant along the lines of Helpman and Itskhoki (2010) and Helpman, Itskhoki, and Redding (2010). On the other hand, firms can install a screening technology for improving the quality of worker-task matches, by making an investment $f_\mu$ which is endogenous.

### 3.2.2 Equilibrium in the closed economy

After the lottery, the baseline productivity is revealed, and the firm either stays out of the market or it decides to produce, sets its employment level $l(\omega)$ and chooses its screening effort $\mu(\omega)$ to maximize profits

$$\pi(\omega) = p(\omega)x(\omega) - wl(\omega) - [1+\mu(\omega)]^\gamma - f \tag{3.7}$$

subject to (3.2), (3.6), and a set of common non-negativity constraints. The (interior) solution to this maximization problem is given by the two first-order conditions:

$$\pi_l(\omega) = \frac{\sigma-1}{\sigma} p(\omega)\phi(\omega)\left[1+\mu(\omega)\right] - w = 0, \tag{3.8}$$

$$\pi_\mu(\omega) = \frac{\sigma-1}{\sigma} p(\omega)l(\omega)\phi(\omega) - \gamma\left[1+\mu(\omega)\right]^{\gamma-1} = 0. \tag{3.9}$$

Being interested in interior solutions, we must ensure that all firms find it attractive to implement a screening technology. Intuitively, this requires that the costs of screening applicants must be small relative to production fixed costs $f$. To put it more formally, all firms find it attractive to screen their applicants at least a little bit if $(1+f)(\sigma-1) > \gamma$. Furthermore, to avoid that (all) firms make an infinitively high investment into screening, the additional costs of further increasing the screening effort must exceed the additional benefits of doing so at high levels of $\mu(\omega)$, which is the case if $\gamma > \sigma - 1$. In the appendix, we derive the two conditions and show that for the respective parameter domain, $\pi(\omega)$ has a unique interior maximum in $(l,\mu)$-space.

With these insights at hand, we can proceed with rewriting first-order condition (3.8) as follows:

$$p(\omega) = \frac{\sigma}{\sigma-1}\,\frac{w}{\phi(\omega)\left[1+\mu(\omega)\right]}. \tag{3.10}$$

Hence, in line with textbook models of monopolistic competition, firms set prices as a constant markup on marginal costs, which in our setting are inversely related to the firms' screening effort $\mu(\omega)$. First-order condition (3.9) determines the profit-maximizing screening effort $\mu(\omega)$, and accounting for (3.6), we can reformulate the respective condition to

$$r(\omega) = \frac{\sigma\gamma}{\sigma-1}\left[1+\mu(\omega)\right]^\gamma, \tag{3.11}$$

where $r(\omega) = p(\omega)x(\omega)$ denotes revenues of firm $\omega$. Eq. (3.11) establishes a positive relationship between firm-level revenues and screening expenditures. Combining (3.2), (3.10), and (3.11), we get:

$$\frac{r(\omega_1)}{r(\omega_2)} = \left(\frac{1+\mu(\omega_1)}{1+\mu(\omega_2)}\right)^\gamma, \qquad \frac{r(\omega_1)}{r(\omega_2)} = \left(\frac{\phi(\omega_2)\left[1+\mu(\omega_2)\right]}{\phi(\omega_1)\left[1+\mu(\omega_1)\right]}\right)^{1-\sigma}. \tag{3.12}$$

These two expressions jointly determine relative screening effort and relative revenues of firms 1 and 2 as functions of these firms' baseline productivity ratio. This implies that heterogeneity of the two firms is fully characterized by their baseline productivity differential, and we can therefore use productivity $\phi$ to index firms from now on. Hence, we can rewrite (3.12) in the following way:

$$\frac{1+\mu(\phi_1)}{1+\mu(\phi_2)} = \left(\frac{\phi_1}{\phi_2}\right)^{\frac{\sigma-1}{\gamma-\sigma+1}}, \qquad \frac{r(\phi_1)}{r(\phi_2)} = \left(\frac{\phi_1}{\phi_2}\right)^{\frac{\gamma(\sigma-1)}{\gamma-\sigma+1}}. \tag{3.13}$$

Since $\gamma > \sigma - 1$ is a prerequisite for finite screening investment, we can conclude that in an interior equilibrium firms with higher $\phi$-levels make higher revenues and choose a higher screening effort. This is well in line with evidence, for example, by Barron, Black, and Loewenstein (1987), who document a positive relationship between expenditures in screening workers and employer size. Furthermore, the model is also consistent with the finding that workers are more productive in larger firms (see Idson and Oi, 1999), pointing to the role of better matching quality for explaining this size differential.

To separate active from inactive firms we can characterize a marginal producer, who is indifferent between starting production and remaining inactive. We denote the productivity of this firm by $\phi^*$, which we refer to by the term *cutoff productivity level.* The zero-cutoff profit condition, which characterizes this firm, is given by $r(\phi^*)/\sigma = f + [1+\mu(\phi^*)]^\gamma$. We can combine this indifference condition with (3.11) to explicitly solve for screening effort and revenues of the marginal producer:

$$1+\mu(\phi^*) = \left(\frac{f(\sigma-1)}{\gamma-\sigma+1}\right)^{\frac{1}{\gamma}}, \qquad r(\phi^*) = \frac{\sigma\gamma f}{\gamma-\sigma+1}. \tag{3.14}$$

In view of (3.13) and (3.14), we can calculate average profits of active producers, $\bar{\pi}$. Defining $\xi \equiv \gamma(\sigma-1)/(\gamma-\sigma+1)$ , we obtain[9]

$$\bar{\pi} = \frac{f\xi}{\nu-\xi}, \tag{3.15}$$

where $\nu > \xi$ is assumed to ensure a finite positive level of $\bar{\pi}$. Furthermore, free entry into the productivity lottery requires that, in equilibrium, the expected return to entry $(1-G(\phi^*))\,\bar{\pi}$ equals the participation fee $f_e$. Therefore, the free entry condition in our static model reads

$$\bar{\pi} = f_e(\phi^*)^\nu. \tag{3.16}$$

Together, Eqs. (3.15) and (3.16) determine $\bar{\pi}$ and $\phi^*$. This completes the characterization of firm-level variables in the closed economy, and we can now turn to studying the main economy-wide variables of interest: welfare and underemployment, arising from the firm-internal mismatch of workers and tasks.

With just a single consumption good, per-capita income is a suitable measure for utilitarian welfare. Since aggregate profits equal total expenditures for the lottery participation fee and the price of final output equals one, according to our choice of numéraire, per-capita income equals wage rate $w$ in our setting. To solve for the wage rate, we can combine $r(\phi^*) = p(\phi^*)x(\phi^*)$ and $Y = Mr(\phi^*)\nu/(\nu-\xi)$. Substituting (3.2) and (3.10) and accounting for (3.14)-(3.16), we can calculate

$$w = \frac{\sigma-1}{\sigma}\left(\frac{\nu}{\nu-\xi}\right)^{\frac{1}{\sigma-1}}[1+\mu(\phi^*)]\,\phi^* = \frac{\sigma-1}{\sigma}\left(\frac{\nu}{\nu-\xi}\right)^{\frac{1}{\sigma-1}}\left(\frac{f\xi}{f_e(\nu-\xi)}\right)^{\frac{1}{\nu}}\left(\frac{f\xi}{\gamma}\right)^{\frac{1}{\gamma}}. \tag{3.17}$$

[9]Derivation details are deferred to the appendix.

According to (3.17), our model gives rise to the somewhat counter-intuitive results that an increase in production fixed costs $f$ provides a stimulus for per-capita income (and thus utilitarian welfare). The reason for this outcome is that firm entry exerts a negative externality on the output of incumbent firms, who end up being too small relative to the social optimum. In other models of monopolistic competition, this negative externality is counteracted by a positive externality due to stronger labor division in the production of final output (see Ethier, 1982), and the two externalities exactly offset when applying the technology in Matusz (1996). Final goods production does not give rise to an external scale effect in our setting, and hence the model considered here lacks a positive externality of firm entry, implying that the mass of producers deviates from the social optimum.[10] Higher production fixed costs imply that firms must be more productive in order to survive in the market. This improves the composition of active producers, which is to the benefit of consumers in our setting.

To obtain an economy-wide measure of mismatch between workers and tasks, we compute the *average* distance between task-specific skill requirements and worker-specific abilities. As formally shown in the appendix, this aggregate measure of mismatch is given by

$$u = \frac{1}{3\left[1+\mu(\phi^*)\right]} \frac{\gamma(\nu-\xi)}{\gamma(\nu-\xi)+\xi} = \frac{1}{3}\left(\frac{\gamma-\sigma+1}{f(\sigma-1)}\right)^{\frac{1}{\gamma}} \frac{\gamma(\nu-\xi)}{\gamma(\nu-\xi)+\xi}, \tag{3.18}$$

where the second equality follows from (3.14). The existence of underemployment due to a mismatch of abilities and skill-requirements is the main difference between our setting and an otherwise identical Melitz (2003) framework with homogeneous workers and a single-task production technology. The source of underemployment also differs from other models that introduce search frictions into a Melitz framework (see, for instance, Helpman and Itskhoki, 2010; Helpman, Itskhoki, and Redding, 2010; Felbermayr, Prat, and Schmerer, 2011). In our setting, it is not the existence of recruitment costs *per se* but rather the mismatch of worker-specific abilities and task-specific skill requirements in the production of goods that generates an inefficient allocation of labor and thus underemployment. This completes the analysis of the closed economy.

## 3.3 The open economy

### 3.3.1 Basic structure and preliminary insights

In this chapter, we consider trade between two fully symmetric countries, whose economies are as characterized in the previous chapter. There are no impediments to the international transaction of final goods, whereas exporting of intermediates involves two types of costs: On the one hand, there are fixed costs $f_x > 0$ (in units of final output) for setting up a foreign distribution network and, on the other hand, there are iceberg transport costs, which imply that $\tau > 1$ units of intermediate goods must be shipped in order for one unit to arrive in the foreign economy. Both of these costs are also present in the Melitz (2003) framework and – in combination with the heterogeneity of firms in their baseline productivity levels – they generate self-selection of only the best (most productive) producers into exporting, provided

[10] Combining the labor market clearing condition with the constant markup rule, gives $wL\sigma/(\sigma-1) = Mr(\phi^*)\nu/(\nu-\xi)$, which in view of (3.14) and (3.17), can be solved for the mass of firms $M$:

$$M = \frac{\sigma-1}{\sigma}\left(\frac{\nu}{\nu-\xi}\right)^{\frac{2-\sigma}{\sigma-1}} \left(\frac{f\xi}{\gamma}\right)^{\frac{1}{\gamma}} \left(\frac{f\xi}{f_e(\nu-\xi)}\right)^{\frac{1}{\nu}} \frac{L}{\xi f}.$$

that these costs are sufficiently high. The decision to start exporting is more sophisticated in our setting, because it influences a firm's optimal choice of screening effort and thus exerts a feedback effect on profits attainable in the domestic market. Hence, there is an interdependence between the decision to export and a firm's performance in its domestic market, which does not exist in Melitz (2003). Due to this interdependence, we have to distinguish between variables referring to exporters (denoted by superscript $e$) and non-exporters (denoted by superscript $n$). Furthermore, we use subscript $x$ to refer to variables associated with foreign market sales of an exporter, while domestic variables are index free.

Holding economy-wide variables constant, access to exporting does not affect a non-exporter's profit-maximizing choice of $l(\phi)$ and $\mu(\phi)$ as characterized by (3.8) and (3.9). Things are different for an exporter, who realizes revenues $r^e(\phi)$ and $r^e_x(\phi) = \tau^{1-\sigma} r^e(\phi)$ in the domestic and foreign market, respectively, implying that in the open economy this firm's profit-maximizing choice of $\mu(\phi)$ is given by

$$\left(1+\tau^{1-\sigma}\right) r^e(\phi) = \frac{\sigma\gamma}{\sigma-1}\left[1+\mu^e(\phi)\right]^\gamma \tag{3.19}$$

instead of (3.11). However, since condition (3.19) is structurally the same for all exporters, we can conclude that the ratio of screening effort and the ratio of total revenues in (3.13) remain unaffected in the open economy, when comparing two firms of the same export status ($n$ or $e$) but differing productivity levels. In contrast, when comparing two firms with the same baseline productivity but differing export status, we obtain

$$\frac{1+\mu^e(\phi)}{1+\mu^n(\phi)} = \left(1+\tau^{1-\sigma}\right)^{\frac{1}{\gamma-\sigma+1}} \qquad \frac{r^e(\phi)}{r^n(\phi)} = \left(1+\tau^{1-\sigma}\right)^{\frac{\sigma-1}{\gamma-\sigma+1}}. \tag{3.20}$$

From the analysis of the closed economy we know that a firm's screening effort increases with its revenues. Since, all other things equal, exporting generates additional revenues from sales to foreign consumers, it renders screening more attractive, resulting in $\mu^e(\phi) > \mu^n(\phi)$. On the other hand, the higher screening effort under exporting improves the quality of worker-task matches and thus lowers unit production costs. This stimulates sales in both the domestic and the foreign market, implying $r^e(\phi) > r^n(\phi)$ in Eq. (3.20). Hence, there is a positive feedback effect of exporting on domestic revenues, and this raises the incentives of firms to serve foreign consumers.

Despite the additional complexity arising from the feedback effect that a firm's exporting decision exerts on its domestic profits, our model preserves key properties of the Melitz (2003) model, regarding the partitioning of firms by export status. To see this, we can make use of (3.11), (3.13), (3.14), (3.19), and (3.20) and write a firm's profit gain from exporting, $\Delta\pi(\phi) \equiv \pi^e(\phi) - \pi^n(\phi)$, as follows:

$$\Delta\pi(\phi) = \left[\left(1+\tau^{1-\sigma}\right)^{\frac{\xi}{\sigma-1}} - 1\right]\left(\frac{\phi}{\phi^*}\right)^\xi f - f_x. \tag{3.21}$$

The profit differential in (3.21) increases in $\phi$, and we can thus conclude that if the two trade cost parameters, $f_x$ and $\tau$, are sufficiently high, there is self-selection of only the most productive firms into exporting as in other applications of the Melitz model. This is the case we are focussing on in this chapter, and we can therefore characterize a firm that is indifferent between exporting and non-exporting: $\Delta\pi(\phi) = 0$. We denote the (cutoff) productivity of this firm by $\phi^*_x$, implying that firms with $\phi > \phi^*_x$ end up being exporters, while firms with $\phi < \phi^*_x$ end up being non-exporters. Solving $\Delta\pi(\phi^*_x) = 0$ for the ratio between the two productivity cutoffs $\phi^*_x$

and $\phi^*$, we obtain

$$\frac{\phi_x^*}{\phi^*} = \left( \frac{f_x/f}{\left(1+\tau^{1-\sigma}\right)^{\frac{\xi}{\sigma-1}} - 1} \right)^{\frac{1}{\xi}}, \tag{3.22}$$

and there is partitioning of firms by export status if $\phi_x^*/\phi^* > 1$. Furthermore, we can use the productivity ratio in (3.22) to calculate the share of exporting firms in the open economy: $\chi \equiv [1 - G(\phi_x^*)]/[1 - G(\phi^*)] = (\phi_x^*/\phi^*)^{-\nu}$. This gives

$$\chi = \left\{ \frac{f}{f_x} \left[ \left(1+\tau^{1-\sigma}\right)^{\frac{\xi}{\sigma-1}} - 1 \right] \right\}^{\frac{\nu}{\xi}}. \tag{3.23}$$

From (3.22) and (3.23), we can conclude that higher trade cost costs, i.e. a higher fixed exporting cost $f_x$ or a higher iceberg transport cost parameter $\tau$, raise the minimum productivity level that is necessary to render exporting an attractive choice, thereby lowering the share of exporters in the total population of active firms, $\chi$. With this insights at hand, we are now equipped to solve for the open economy equilibrium.

### 3.3.2 The open economy equilibrium

The equilibrium in the open economy is characterized by a two-stage entry mechanism that is similar to the closed economy, but additionally involves the decision to start exporting or to sell exclusively to the domestic market (at stage 2). Access to the export market raises profits of the most productive producers, and this provides a stimulus for the average profit of active firms, which in the open economy are given by[11]

$$\bar{\pi} = \frac{f\xi}{\nu - \xi} \left( 1 + \chi \frac{f_x}{f} \right) \tag{3.24}$$

instead of (3.15). Combining Eq. (3.24) with the free entry condition in (3.16), we can calculate cutoff productivity $\phi^*$ in the open economy and contrast it with its closed economy counterpart, $\phi_a^*$ (where index $a$ refers to autarky): $\phi^*/\phi_a^* = (1 + \chi f_x/f)^{1/\nu}$. Hence, opening up to trade with a symmetric partner country leads to an upward shift in the cutoff productivity level $\phi^*$. The mechanism behind this effect is well understood from Melitz (2003). Access to exporting generates additional demand for labor, and hence firms at the lower bound of the productivity distribution have to leave the market in order to restore the labor market equilibrium. This points to an important asymmetry of how firms are affected by trade liberalization. Whereas the most productive firms experience a profit gain due to access to the export market, the least productive ones experience a profit loss due to stronger competition for scarce labor in the open economy.

To shed further light on the asymmetry in the firm-level response to trade, we can study how producers adjust their internal labor market in the open economy. We start with a closer look on non-exporting firms. Provided that the marginal firm in the market is not exporting, its screening effort remains to be given by (3.14). However, the new marginal producer has a higher baseline productivity than the marginal producer in the closed economy, and hence its screening effort is definitely lower than under autarky. Furthermore, since the link between the ratio of screening effort and the ratio of baseline productivities among non-exporting firms remains to

[11] Derivation details are deferred to the appendix.

be given by (3.13), it is clear that all non-exporting firms respond to the trade shock with a reduction in their screening effort. This is intuitive, as the sales level of non-exporting firms declines in the open economy, so that these firms are not willing to keep the (relatively) expensive screening technology they have installed in the closed economy. Contrasting the screening effort of a non-exporter in the closed and the open economy, we can compute:

$$\frac{1+\mu^n(\phi)}{1+\mu^a(\phi)} = \left(\frac{1}{1+\chi f_x/f}\right)^{\frac{\xi}{\gamma\nu}} < 1. \tag{3.25}$$

Calculating the screening differential for an exporting firm, we obtain

$$\frac{1+\mu^e(\phi)}{1+\mu^a(\phi)} = \left(\frac{\left(1+\tau^{1-\sigma}\right)^{\frac{\nu}{\sigma-1}}}{1+\chi f_x/f}\right)^{\frac{\xi}{\gamma\nu}} = \left(\frac{\left(1+\chi^{\xi/\nu} f_x/f\right)^{\frac{\nu}{\xi}}}{1+\chi f_x/f}\right)^{\frac{\xi}{\gamma\nu}}, \tag{3.26}$$

where the second equality follows from Eq. (3.23). Noting that $\nu > \xi$ holds by assumption, it is straightforward to show that $\mu^e(\phi) > \mu^a(\phi)$: A firm that starts exporting in the open economy realizes higher revenues and thus raises its screening effort relative to autarky. The differential impact of trade on screening effort of non-exporting and exporting firms is graphically depicted by Figure 3.1 and summarized in Proposition 4.[12]

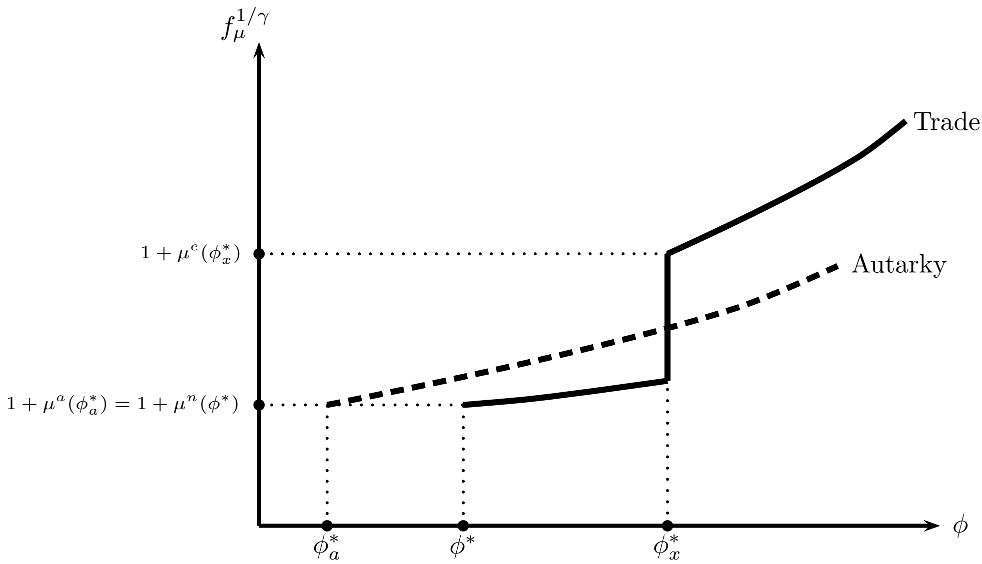


Figure 3.1: The impact of trade on firm-level screening effort

**Proposition 4** *A country's opening up to trade, leads to an asymmetric response in the firm-internal allocation of workers to tasks. Whereas exporters expand their screening effort and thus improve the quality of worker-task matches, non-exporters reduce their screening effort and accept a larger mismatch between skill requirements and abilities in the performance of tasks.*

[12]For illustrative purposes, we have assumed $\xi > \gamma$, whereas in general $\xi >, =, < \gamma$ is possible.

**Proof.** Analysis in the text. ■

Due to asymmetric firm-level consequences, it is clear that access to trade exerts counteracting effects on the general equilibrium variables of interest: wage rate (welfare) $w$ and underemployment $u$. Similar to the autarky scenario, the wage rate in the open economy, can be derived by combining $r(\phi^*) = p(\phi^*)x(\phi^*)$ with the adding up condition $Y = M(1+\chi f_x/f)r(\phi^*)\nu/(\nu-\xi)$. Substituting (3.2) and (3.10) – with $M(1+\chi)$ presuming the role of $M$ in the open economy – and accounting for (3.14), (3.16), and (3.24), we can calculate

$$w = \left(\frac{1+\chi f_x/f}{1+\chi}\right)^{\frac{1}{\sigma-1}} \left(1+\chi\frac{f_x}{f}\right)^{\frac{1}{\nu}} w_a. \tag{3.27}$$

Hence, gains from trade are guaranteed if $f_x/f \geq 1$, while losses from trade cannot be ruled out if $f_x/f < 1$.[13] Trade can be welfare-deteriorating in our setting, because under production technology (3.1) the outcome of decentralized firm entry is not socially optimal. To the extent that trade aggravates the distortion of firm entry, the resulting welfare loss may outweigh the welfare stimulus from market integration (cf. Shy, 1988). In our setting, the existence of *net* gains from trade depends on the relative strength of two selection effects. On the one hand, there is selection of the best producers into exporting, which raises labor demand ceteris paribus. On the other hand, there is selection of the least productive firms out of the market, which lowers labor demand. The two selection effects are interdependent and their relative strength depends on fixed cost ratio $f_x/f$. If this fixed costs ratio is sufficiently high, it is the selection into exporting that dominates rendering the overall effect of trade on labor demand and thus welfare positive.

As outlined in Proposition 4, there are asymmetric firm-level effects of trade on the mismatch between abilities and skill requirements. Exporting firms increase their screening expenditures, and hence their matching outcome is improved. The opposite is true for non-exporting firms. However, there is an additional positive effect on economy-wide underemployment because labor is relocated towards exporting firms in the open economy and, due to this change in labor composition, the overall impact of trade on the average quality of worker-task matches is positive. To see this, we can explicitly solve for our measure of underemployment in the open economy. As formally shown in the appendix, we get:

$$u = \frac{1+a(\tau)\chi^{1+\xi/(\nu\gamma)} f_x/f}{1+\chi f_x/f} u^a, \qquad \text{with} \quad a(\tau) \equiv \frac{\left(1+\tau^{1-\sigma}\right)^{\frac{(\gamma-1)\xi}{\gamma(\sigma-1)}}-1}{\left(1+\tau^{1-\sigma}\right)^{\frac{\xi}{\sigma-1}}-1}. \tag{3.28}$$

Noting that $a(\tau) < 1$, it is immediate that $u < u_a$, which proves that trade reduces the *average* mismatch between task-specific skill requirements and worker-specific abilities, thereby lowering underemployment.

We can summarize the main insights from our analysis as follows.

**Proposition 5** *Opening up to trade improves the average quality of worker-task matches, thereby reducing economy-wide underemployment due to a misallocation of workers to tasks. The impact of trade on welfare is not clear-cut in general. Only if fixed costs of exporting relative to production fixed costs, $f_x/f$, are sufficiently high, there are gains from trade in our setting.*

[13] For instance, with a parametrization of $\nu = 8$, $\sigma = 3$, $\tau = 1.5$, and $\gamma = 10$, there are losses from trade if $f_x/f \leq 0.77$ – with $f_x/f \geq 0.58$ establishing selection of only the most productive firms into export status, i.e. $\chi \in (0,1)$.

**Proof.** Analysis in the text. ■

We complete the analysis in this chapter by shedding light on the consequences of a marginal reduction in transport cost parameter $\tau$. Such a decline increases expected income from exporting, and thus raises $\chi$, according to (3.23), as well as average profit income $\bar{\pi}$, according to (3.24). On the other hand, there is a stimulus on labor demand, which enforces additional market exit at the lower bound of the productivity distribution and therefore leads to an upward shift in cutoff productivity $\phi^*$. Furthermore, a marginal decline in the iceberg transport cost parameter augments the heterogeneity in screening effort between non-exporting and exporting producers, according to (3.20). With respect to adjustments in the wage rate, we can infer from (3.27) that $dw/d\tau < 0$ if $f_x/f > 1$. In this case, a gradual reduction in the iceberg transport cost parameter exerts a positive monotonic impact on welfare. In contrast, if $f_x/f < 1$, changes in $\tau$ need not exert a monotonic impact on $w$. Finally, from the analysis above we know that a country's movement from autarky to trade with an arbitrary transport cost level unambiguously improves the average quality of worker-task matches. We can therefore safely conclude that a marginal decline in $\tau$ must lower $u$ if transport costs have been large initially. In the appendix we show that this effect extends to the case where $\tau$ has already been low prior to the fall in the iceberg transport cost parameter, so that a gradual decline in $\tau$ reduces underemployment $u$ monotonically.

## 3.4 A model variant with involuntary unemployment

In this chapter, we introduce search frictions as an additional source of inefficiency in the allocation of labor to show how mismatch between the abilities of workers and the skill requirements of tasks interact with traditional forms of underemployment. For this purpose, we consider a competitive search model along the lines of Rogerson, Shimer, and Wright (2005), in which firms post wages and workers direct their search to the most attractive employer to queue for a job, there.[14] The mass of matches between workers and jobs, $m$, depends positively on the number of applicants, $s$, and the number of open vacancies, $v$. In the interest of analytical tractability, we choose a Cobb-Douglas specification and write $m(s,v) = As^{1-\zeta}v^{\zeta}$, where $\zeta, A \in (0,1)$ are the same for all producers.[15] Measuring by $q \equiv s/v$ the queue length of workers applying for jobs, the probability of the firm to fill a specific vacancy is given by $\alpha_e(q) \equiv m(s,v)/v = Aq^{1-\zeta}$. In our static model, this equals the share of vacancies filled in the respective firm. The probability of a worker to be hired, when queuing for a job, is given by $\alpha_w(q) \equiv m(s,v)/s = Aq^{-\zeta}$. In the subsequent analysis we focus on interior solutions with $\alpha_e(q), \alpha_w(q) \in (0,1)$. For which parameter domain such an interior solution is realized will be discussed below.

Setting unemployment compensation equal to zero and denoting by $V$ the highest income a worker can expect when applying for a job at a different firm, queuing for vacancies in a firm with productivity $\phi$ is only attractive for the worker if $V \leq \alpha_w[q(\phi)]w(\phi)$. Since firms set the same wage for all workers in our setting (see above), additional workers apply for jobs in this

[14] Rogerson, Shimer, and Wright (2005) provide an excellent overview of different search-theoretic approaches, their main advantages and disadvantages. In the context of heterogeneous firms, a competitive search model has also been considered by Ritter (2011) and Felbermayr, Impulliti, and Prat (2012).

[15] In a competitive search model it is not necessary to choose an ad hoc specification of the matching function. Instead, one can as well take the coordination problem of directed search seriously and provide a clean microfoundation of this problem by choosing an urn-ball matching function (see Peters, 1991, for an early contribution and King and Stähler, 2010, for an application in the context of trade). A disadvantage of this more advanced approach is its lower analytical tractability, and we therefore prefer treating the matching function as a black box as it is still common in the literature.

firm as long as the inequality is strict. This lowers the probability of being hired by the firm, $\alpha_w[q(\phi)]$, and the adjustment process continues until the expected return of workers is the same in all active firms. Hence, $V = Aq(\phi)^{-\zeta}w(\phi)$ must hold in equilibrium, and the directed search mechanism therefore establishes a positive link between queue length $q(\phi)$ and the posted wage $w(\phi)$:

$$w(\phi) = \frac{q(\phi)^{\zeta}V}{A}. \tag{3.29}$$

The mass of vacancies set up by a firm with productivity $\phi$, $v(\phi)$, is linked to this firm's employment level, $l(\phi)$, according to $v(\phi) = l(\phi)/[Aq(\phi)^{1-\zeta}]$. The costs of installing and advertising a vacancy are measured in units of final output and are given by $k > 0$.

With these insights at hand, we can write firm-level profits in the closed economy as follows:

$$\pi(\phi) = p(\phi)x(\phi) - \frac{q(\phi)^{\zeta}V}{A}l(\phi) - [1+\mu(\phi)]^{\gamma} - f - \frac{kl(\phi)}{Aq(\phi)^{1-\zeta}}. \tag{3.30}$$

The firm sets $l(\phi)$, $q(\phi)$, and $\mu(\phi)$ simultaneously to maximize profits (3.30) subject to (3.2), (3.6), and a set of non-negativity constraints. The (interior) solution to this maximization problem is characterized by the following three first-order conditions:

$$\pi_l(\phi) = \frac{\sigma-1}{\sigma}p(\phi)\phi\,[1+\mu(\phi)] - w(\phi) - \frac{k}{Aq(\phi)^{1-\zeta}} = 0, \tag{3.31}$$

$$\pi_q(\phi) = -\frac{l(\phi)\zeta q(\phi)^{\zeta-1}V}{A} + (1-\zeta)l(\phi)\frac{k}{Aq(\phi)^{2-\zeta}} = 0, \tag{3.32}$$

$$\pi_\mu(\phi) = \frac{\sigma-1}{\sigma}p(\phi)l(\phi)\phi - \gamma\,[1+\mu(\phi)]^{\gamma-1} = 0. \tag{3.33}$$

Equations (3.29) and (3.32) jointly determine

$$q(\phi) = \frac{(1-\zeta)k}{\zeta V} \equiv q, \qquad w(\phi) = \frac{(1-\zeta)k}{\zeta A q^{1-\zeta}} \equiv w, \tag{3.34}$$

implying that all firms pay the same wage, irrespective of the prevailing productivity differences. This outcome is in line with models of random matching between workers and heterogenous firms, in which wages are determined by individual Nash bargaining. For instance, Felbermayr and Prat (2011, p. 286) point out that in their setting all firms pay the same wage, because "multiple-worker firms exploit their monopsony power until employees are paid their outside option [that] is constant across firms because it depends solely on aggregate outcomes." This gives a prominent role to over-hiring in models with individual wage bargaining, which, however, is not present under wage posting. Instead, in our model the finding of a uniform wage level is a consequence of three model ingredients: linear hiring costs, the same outside option of workers with differing abilities, and the isoelastic demand structure.[16]

[16]There are different possibilities to modify the model such that it gives rise to the empirically well-documented pattern that larger, more productive firms pay higher wages. For instance, one could consider convex instead of linear recruitment costs, as suggested by Helpman and Itskhoki (2010). Alternatively, one could modify the wage setting process and assume that firms post fair wages, as in Egger and Kreickemeier (2009, 2012) and Amiti and Davis (2012). Finally, one could also give up the symmetry of firm-worker matches and instead assume that ability is firm-specific and employers can learn about this ability during the recruitment process by installing a screening technology, as suggested by Helpman, Itskhoki, and Redding (2010). While all of these modifications would allow for firm-specific wage payments, the costs of these extensions in terms of analytical tractability would be enormous, and we therefore decided to stick to the more parsimonious model variant without wage differentiation.

Combining (3.31) and (3.34) gives the modified price-markup rule

$$p(\phi) = \frac{\sigma}{(\sigma-1)\phi\,[1+\mu(\phi)]}\frac{k}{\zeta A q^{1-\zeta}}, \tag{3.35}$$

where marginal labor costs are augmented by recruitment expenditures. Contrasting (3.9) and (3.33), we see that the existence of search frictions does not change the profit-maximizing choice of screening. Since search frictions do also not affect firm entry decisions, cutoff productivity $\phi^*$ and revenues of the marginal firm $r(\phi^*)$ remain to be given by (3.14). Similarly, the zero-cutoff profit condition and the free entry condition remain to be given by (3.15) and (3.16), respectively, and hence neither $\bar{\pi}$ nor $\phi^*$ depend on the prevailing search frictions or the costs of establishing and posting vacancies, $k$.

With the firm-level variables at hand, we can now solve for the general equilibrium outcome in the closed economy. For this purpose, we first look at queue length $q$. Substituting (3.2) into $r(\phi^*) = p(\phi^*)x(\phi^*)$ and accounting for $Y = Mr(\phi^*)\nu/(\nu-\xi)$ gives $p(\phi^*)^{\sigma-1} = \nu/(\nu-\xi)$. Using (3.35) and noting that $\phi^*\,[1+\mu(\phi^*)] = [(f\xi)/\gamma]^{1/\gamma}\,\{(f\xi)/[f_e(\nu-\xi)]\}^{1/\nu}$ follows from (3.14)-(3.16), we can derive

$$q = \left\{\frac{k\sigma}{A\zeta(\sigma-1)}\left(\frac{\nu-\xi}{\nu}\right)^{\frac{1}{\sigma-1}}\left(\frac{f_e}{f}\,\frac{\nu-\xi}{\xi}\right)^{\frac{1}{\nu}}\left(\frac{\gamma}{f\xi}\right)^{\frac{1}{\gamma}}\right\}^{\frac{1}{1-\zeta}}. \tag{3.36}$$

To solve for economy-wide unemployment $\hat{u}$, we can substitute $V = (1-\hat{u})w$ into (3.29). Rearranging terms, yields $1-\hat{u} = Aq^{-\zeta}$, which establishes the intuitive result that a larger queue length at individual firms leads to higher economy-wide unemployment. Accounting for $q$ from (3.36), we can compute

$$1-\hat{u} = \left\{\frac{\zeta(\sigma-1)}{k\sigma}\left(\frac{\nu}{\nu-\xi}\right)^{\frac{1}{\sigma-1}}\left(\frac{f}{f_e}\,\frac{\xi}{\nu-\xi}\right)^{\frac{1}{\nu}}\left(\frac{f\xi}{\gamma}\right)^{\frac{1}{\gamma}}\right\}^{\frac{\zeta}{1-\zeta}} A^{\frac{1}{1-\zeta}}. \tag{3.37}$$

Eq. (3.37) characterizes involuntary unemployment as one important aspect of *under*employment and measures the efficiency loss due to search frictions. However, it does not capture the efficiency loss, arising from a mismatch between workers and tasks in the firm-internal allocation of labor. This form of underemployment can be measured by the average distance between task-specific skill requirements and worker-specific abilities and is represented by $u$. Crucially, the existence of search frictions does not impact firm-level screening (see above), and hence it does not alter firm-internal labor allocation. Due to this, $u$ remains to be given by (3.18) in the closed economy.[17]

Finally, welfare in the closed economy is given by $(1-\hat{u})w$, which, in view of (3.34), (3.36), and (3.37), can be expressed as

$$(1-\hat{u})w = \frac{1-\zeta}{\zeta}\frac{k}{q} = (1-\zeta)A^{\frac{1}{1-\zeta}}\left(\frac{\zeta}{k}\right)^{\frac{\zeta}{1-\zeta}}\tilde{w}^{\frac{1}{1-\zeta}} = (1-\zeta)(1-\hat{u})\tilde{w}, \tag{3.38}$$

[17] Eqs. (3.36) and (3.37) can be used for characterizing the parameter domain that establishes an interior solution with $\alpha_e(q), \alpha_w(q) \in (0,1)$. More specifically, we can conclude that $\alpha_e(q) = Aq^{1-\zeta} < 1$ and $\alpha_w(q) = Aq^{-\zeta} < 1$ simultaneously hold if

$$A^{\frac{1}{\zeta}} < \frac{k\sigma}{\zeta(\sigma-1)}\left(\frac{\nu-\xi}{\nu}\right)^{\frac{1}{\sigma-1}}\left(\frac{f_e}{f}\,\frac{\nu-\xi}{\xi}\right)^{\frac{1}{\nu}}\left(\frac{\gamma}{f\xi}\right)^{\frac{1}{\gamma}} < 1,$$

while the two probabilities are positive if $\zeta, k, A > 0$ (and $\nu > \xi$ as previously assumed).

where $\tilde{w}$ equals the wage rate in the benchmark model with a perfect labor market, given by (3.17). From (3.38) it is obvious that the existence of search frictions reduces per capita labor income and thus welfare in our setting. This completes the discussion of the closed economy.

We now turn to the open economy and shed light on the effects of trade for the two sources of underemployment. Thereby, we impose the same assumptions as in the baseline model and consider two symmetric countries, iceberg transport costs for shipping intermediate goods across borders and fixed exporting costs to generate selection of only the best firms into export status. With these assumptions at hand, we can now repeat the analysis of the closed economy step by step in order to derive the main variables of interest for the open economy. However, since the respective calculations are straightforward, we leave them to the interested reader and only summarize the main results from this analysis, here. From the closed economy, we know that the existence of labor market imperfection does not affect the allocation of workers to tasks, and hence our insights regarding the consequences of trade for the firm-internal mismatch remains unaffected by adding a search friction. This implies that the open economy level of $u$ remains to be given by (3.28).

Furthermore, it is easily confirmed that the existence of a search friction does not alter Eqs. (3.19)-(3.21), therefore leaving the exporting decision unaffected. As a consequence, the share of exporting firms remains to be given by (3.23). Noting from (3.38) that per capita labor income in the more sophisticated model variant with search frictions is a convex function of the wage rate in the benchmark model with a perfect labor market, we can infer the welfare effects of trade by considering Eq. (3.27). To more specific, we can write

$$\frac{(1-\hat{u})w}{(1-\hat{u}^a)w^a} = \left(\frac{\tilde{w}}{\tilde{w}^a}\right)^{\frac{1}{1-\zeta}} = \left[\left(\frac{1+\chi f_x/f}{1+\chi}\right)^{\frac{1}{\sigma-1}}\left(1+\chi\frac{f_x}{f}\right)^{\frac{1}{\nu}}\right]^{\frac{1}{1-\zeta}}. \tag{3.39}$$

Hence, the existence of search frictions does not change the welfare effects of trade in a qualitative way, but it magnifies the (positive or negative) welfare implications identified in Chapter 3.3. To understand, where the additional welfare effect comes from, it is worth noting that we can write

$$\frac{w}{w^a} = \left(\frac{q}{q^a}\right)^{\zeta-1} = \left(\frac{1+\chi f_x/f}{1+\chi}\right)^{\frac{1}{\sigma-1}}\left(1+\chi\frac{f_x}{f}\right)^{\frac{1}{\nu}}, \tag{3.40}$$

according to (3.34) and (3.39). From (3.27) and (3.40) it follows that in the presence of search frictions the wage adjustments triggered by trade are of equal magnitude as in the benchmark model with a perfectly competitive labor market. Therefore, any additional welfare effect must come from adjustments in the employment rate. Looking at

$$\frac{1-\hat{u}}{1-\hat{u}^a} = \left(\frac{q}{q^a}\right)^{-\zeta} = \left(\frac{(1-\hat{u})w}{(1-\hat{u}^a)w^a}\right)^{\zeta} = \left[\left(\frac{1+\chi f_x/f}{1+\chi}\right)^{\frac{1}{\sigma-1}}\left(1+\chi\frac{f_x}{f}\right)^{\frac{1}{\nu}}\right]^{\frac{\zeta}{1-\zeta}} \tag{3.41}$$

provides support for this conclusion. Eqs. (3.39)-(3.41) show that there is a direct link between employment, wage, and welfare effects of trade in our setting. From Chapter 3.3 we know that lacking an external scale effect in the production of final goods, selection of exporters must be sufficiently strong in order for trade to provide a stimulus on aggregate labor demand and equilibrium wages. In this case, the price of the final good falls relative to the wage rate. This lowers the costs of installing and advertising vacancies relative to the costs of compensating workers, and thus alleviates the search friction with positive consequences for aggregate employment.

Both of these effects contribute to a welfare gain if search frictions exist. Things are different if selection effects are weak. In this case, it is possible that labor demand is dampened in the open economy, so that wages decline. However, if wages decline relative to the price of the final good, the establishment of new vacancies becomes less attractive, rendering the search friction more severe than under autarky, with adverse effects on economy-wide employment.

The following proposition summarizes the main insights from the analysis in this chapter.

**Proposition 6** *The existence of search frictions does not alter our insights from the benchmark model regarding the impact of trade on the mismatch between workers and task in the firm-internal labor market. Furthermore, with search frictions, trade triggers wage and employment effects that go into the same direction. As a consequence, the welfare implications of trade, while not altered qualitatively, are reinforced in the model variant with search frictions.*

**Proof.** Analysis in the text. ■

We complete the discussion in this chapter by having a closer look on the specific role played by adjustments in the firm-internal allocation of workers for the impact of trade on welfare and economy-wide unemployment. In particular, we want to shed light on whether one over-estimates or under-estimates the effects of trade, when disregarding the firms' ability to endogenously adjust the quality of worker-task matches. For this purpose, it is worth noting that our model degenerates to one without screening if $\gamma \to \infty$. We can therefore infer insights upon the role played by the firm-internal labor allocation from differentiating (3.39)-(3.41) with respect to $\gamma$. More specifically, we can determine how changes in $\gamma$ alter the employment and welfare effects of trade, by studying the sign of

$$\frac{d(w/w^a)}{d\gamma} = \frac{d(w/w^a)}{d\chi}\frac{d\chi}{d\gamma}. \tag{3.42}$$

Differentiating (3.23) with respect to $\gamma$ gives

$$\frac{d\chi}{d\gamma} = -\frac{\nu\chi}{\gamma}\left\{\frac{1}{\gamma-\sigma+1}\frac{\left(1+\tau^{1-\sigma}\right)^{\frac{\xi}{\sigma-1}}}{\left(1+\tau^{1-\sigma}\right)^{\frac{\xi}{\sigma-1}}-1}\ln\left(1+\tau^{1-\sigma}\right)-\frac{1}{\gamma}\ln\left(\chi^{\frac{\xi}{\nu}}\right)\right\} < 0. \tag{3.43}$$

A higher $\gamma$ implies that fixed costs are more responsive to changes in the screening effort. Accordingly, firms will adjust their screening effort less strongly when facing the opportunity of exporting, so that the fixed cost increase due to exporting is less pronounced (see Eq. (3.20)), and hence the share of exporters increases ceteris paribus if $\gamma$ goes up. On the other hand, the now lower wedge of screening effort eats up part of the productivity advantage of exporters relative to non-exporters, thereby lowering the incentives of firms to sell abroad. In our model, it is the second effect that dominates, so that a higher $\gamma$ reinforces self-selection into exporting, and therefore implies a smaller share of exporting firms $\chi$.

Furthermore, differentiating (3.40) with respect to $\chi$ yields

$$\frac{d(w/w^a)}{d\chi} = \frac{w/w^a}{\nu\left(1+\chi f_x/f\right)\left(1+\chi\right)}\left[\frac{\nu}{\sigma-1}\left(\frac{f_x}{f}-1\right)+(1+\chi)\frac{f_x}{f}\right]. \tag{3.44}$$

It is easily confirmed that the bracket term on the right-hand side of (3.44) is increasing in $f_x/f$, and hence wages increase monotonically in the share of exporting firms if $f_x/f$ (and thus the selection effect) is sufficiently large. In line with our insights from Chapter 3.3, $f_x/f \geq 1$ is sufficient (not necessary) for a monotonically positive impact of an increase in $\chi$ on $w/w^a$.

If such a monotonic effect exists, an increase in $\gamma$ unambiguously lowers the positive wage, employment, and welfare effects of trade, and hence positive economy-wide effects would be underestimated if one ignores endogenous adjustments in the firm-internal allocation of workers to tasks. However, if the impact of a higher $\chi$ on $w/w^a$ is non-monotonic, things are even more worrying, because in this case ignoring endogenous adjustments in the way workers are assigned to tasks may give wrong predictions regarding the existence of positive wage, employment, and welfare effects of trade. The following proposition summarizes these results.

**Proposition 7** *The ability of firms to adjust the quality of worker-task matches leads to weaker selection of firms into exporting, and thus a larger share of exporting firms. Provided that an increase in the share of exporting firms exhibits a positive monotonic impact on wages, adjustments in the firm-internal allocation of workers to tasks therefore strengthen the employment and welfare stimulus relative to a model where such adjustments do not exist. If the relationship between the share of exporting firms and wages is non-monotonic, adjustments in the firm-internal allocation of labor may reverse the employment and welfare effects of trade.*

**Proof.** Analysis in the text. ■

## 3.5 A calibration exercise

In this chapter, we aim at quantifying the effects of trade in our setting. For this purpose, we calibrate our model, using parameter estimates from the literature. A first set of useful parameter estimates is provided by Egger, Egger, and Kreickemeier (2011). Egger, Egger, and Kreickemeier (2011) structurally estimate the main parameters of a trade model with heterogeneous firms and labor market imperfections due to a fair-wage effort mechanism, using firm-level data from five European countries – Bosnia and Herzegovina, Croatia, France, Serbia, and Slovenia – for the period 2000 to 2008. For our calibration exercise, we consider the parameter estimates for France, which hosts the majority of firms in the respective data-set. A first parameter available from the empirical application in Egger, Egger, and Kreickemeier (2011) is the elasticity of substitution, for which they report a value of $\sigma = 6.7$. This estimate is similar to other findings in the literature (see, for instance, Broda and Weinstein, 2006). Furthermore, using the structural relationship between revenues of exporting firms, Egger, Egger, and Kreickemeier (2011) estimate an analogon to $\xi/\nu$, for which they report a value of 0.87, when relying on information for French firms. This is fairly close to the estimate of 0.83 reported by Arkolakis and Muendler (2010) for Brazilian firms.

Unfortunately, there are no direct estimates available for $\gamma$, and we are therefore not able to calculate the parameter values for $\gamma$ and $\nu$ separately. However, from the formal discussion in Chapter 3.2 we can infer that existence of an interior solution requires a sufficiently high level of $\nu$. With $\xi/\nu = 0.87$, $\nu$ must be larger than 6.5 in our calibration exercise. Since we cannot further confine the possible parameter values, we consider three parameter values that are in line with this constraint and choose $\nu = 7$, $\nu = 9$ and $\nu = 11$ for our calibration exercise.[18] Taking account of $\sigma = 6.7$ and $\xi/\nu = 0.87$, we can then calculate the corresponding $\gamma$-levels: $\gamma = 89.01$ for $\nu = 7$, $\gamma = 20.95$ for $\nu = 9$ and $\gamma = 14.10$ for $\nu = 11$.

An additional variable of interest is the share of exporters, $\chi$. Eaton, Kortum, and Kramarz (2011) report from official administrative statistics that 15 percent of French manufacturing firms were exporters in 1986. Egger, Egger, and Kreickemeier (2011) find a significantly larger

[18]These $\nu$-values are well in line with shape parameters of the productivity distribution applied in other numerical applications of the Melitz (2003) model. For instance, Arkolakis and Muendler (2010) consider 5 and 8 as low and high values for the shape parameter, whereas Felbermayr and Prat (2011) consider a value of 9.23.

share of exporters, using the Amadeus data-set. According to their data-base, 45 percent of French firms did export in the average year between 2000 and 2008. Since it is well known that the Amadeus data is biased towards large, incorporated firms, we consider the evidence provided by Eaton, Kortum, and Kramarz (2011) to be more reliable and accordingly set $\chi = 0.15$ in our calibration exercise. Recent empirical research aims at estimating compulsory measures of the iceberg trade cost parameter $\tau$ by employing information on observed international trade flows into a structural gravity equation. Existing results from this literature suggest setting $\tau = 1.5$ (see, for instance, McGowan and Milner, 2013; Novy, 2013). With the iceberg trade cost parameter and the share of exporters at hand, we can then compute a theory-consistent value of fixed cost ratio $f_x/f$. Using the parameter values from above, we obtain $f_x/f = 0.93$ if $\nu = 7$, $f_x/f = 0.96$ if $\nu = 9$, and $f_x/f = 0.98$ if $\nu = 11$. Finally, we follow common practice in the search literature and set $\zeta = 0.5$ (see Petrongolo and Pissarides, 2001, for supportive empirical evidence).

Table 3.1: Quantifying the impact of trade on welfare and under-employment

| Parameter values | | | Changes in percent | | |
|---|---|---|---|---|---|
| $\nu$ | $\gamma$ | $f_x/f$ | $\Delta(1-\hat{u})w$ | $\Delta(1-\hat{u})$ | $\Delta u$ |
| 7 | 89.01 | 0.93 | 3.45 | 1.71 | −0.37 |
| 9 | 20.95 | 0.96 | 2.81 | 1.39 | −1.54 |
| 11 | 14.10 | 0.98 | 2.45 | 1.22 | −2.29 |

*Notes:* An exporter share of $\chi = 0.15$, an iceberg trade cost parameter of $\tau = 1.5$, a $\sigma$-value of 6.7, a $\zeta$-value of 0.5, and a parameter ratio $\xi/\nu = 0.87$ have been considered for computing the figures in this table.

Table 3.1 summarizes the main insights from our calibration exercise and reports employment and welfare effects associated with a movement of France from autarky to its observed degree of openness: $\chi = 0.15$. From Column 4 we see that gains from trade seem to be rather small in our setting, which at least partly may be explained by the absence of external scale economies in the production of final goods. However, the welfare gains documented in Table 3.1 are in the range of welfare effects reported by Eaton and Kortum (2002), who set up a multi-country Ricardian model for 19 OECD economies and investigate how much countries in their data-set would lose if trade were entirely abolished. They compute losses ranging from 0.2 percent for Japan and 10.3 percent for Belgium, and for France they report a welfare loss of 2.5 percent. This is fairly close to the welfare loss from abolishing trade entirely when setting $\nu = 11$ in our model, which amounts to 2.4 percent.

The effects of trade on economy-wide employment are reported in Column 5. At a first glance, the employment effects may seem not sizable. However, it is noteworthy that evaluated at a current unemployment rate of about 10 percent, an employment effect of $\Delta(1-\hat{u}) = 1.22$ (for $\nu = 11$) implies that the observed degree of openness has lowered the French unemployment rate by 1.1 percentage points relative to autarky. Column 6 reports our calibration results for the impact of trade on the average mismatch in the firm-internal allocation of workers to tasks. In line with our theoretical result, this mismatch is reduced in the open economy and the more so, the larger is $\nu$. This is intuitive, as we see from Column 2 that higher levels of $\nu$ are associated with smaller levels of $\gamma$ and thus a smaller elasticity of screening costs in screening effort. As a consequence, for higher values of $\nu$ firms will adjust their screening effort more strongly to new exporting opportunities, leading to a more pronounced reduction in the economy-wide mismatch of workers and tasks in response to trade.

For providing insights on the extent to which adjustments in the firm-internal allocation of workers govern the employment and welfare implications of trade in our setting, we can contrast the findings in Table 3.1 with those from an otherwise identical model variant in which such adjustments are not feasible. For this purpose, we look at the limiting case of $\gamma \to \infty$, which, as outlined in the previous chapter, implies that producers do not screen their applicants, so that $\mu(\phi) = 0$ for all $\phi$. Considering $\nu = 11$ as the preferred value for the shape parameter of the Pareto productivity distribution and thus setting $f_x/f = 0.98$ according to Table 3.1, we can compute a theory-consistent share of exporters that corresponds to the parameter values at hand. We compute $\chi = 0.02$, which confirms our insight from the formal analysis that higher levels of $\gamma$ lower the share of exporters monotonically (see Eq. (3.43)). From the analysis in Chapter 3.4, we are warned that changes in the share of exporting firms need not exhibit a monotonic effect on employment and welfare if $f_x/f < 1$, which is the case in our exercise. It is therefore *a priori* not clear whether the movement of France from autarky to the observed degree of openness would have been beneficial in the absence of screening. In the numerical application, we can evaluate the welfare and employment effects of trade for the limiting case of $\gamma \to \infty$. For the preferred parametrization, this gives $\Delta(1 - \hat{u})w = 0.28$ and $\Delta(1 - \hat{u}) = 0.14$, respectively. Therefore, eliminating the ability of firms to screen their workforce and endogenously adjust the quality of worker-task matches would not alter the welfare and employment effects of trade qualitatively, but it would lead to a significant decline of its beneficial consequences. Finally, recollecting from Chapter 3.4 that gains from trade in our model are a composite of positive employment and positive wage effects, we can ask which of these two partial effects is the more important source of welfare stimulus. The answer to this question is simple. Setting $\zeta = 0.5$, we obtain $\Delta(1 - \hat{u}) = \Delta w$, according to (3.40) and (3.41). Since $\Delta w$ corresponds to the welfare effect of trade in the absence of search frictions, we can therefore conclude that disregarding labor market imperfections leads to a significant downward bias in the calibrated welfare effects of trade.

## 3.6 Concluding remarks

This chapter sets up a model of heterogeneous firms along the lines of Melitz (2003) and enriches this workhorse of modern trade theory by associating production with a continuum of tasks that differ in their skill requirements. Furthermore, we assume that workers differ in their abilities to perform these tasks, and firms therefore face the complex problem of matching heterogeneous workers with heterogeneous tasks. To solve this allocation problem in a satisfactory way, firms require information about worker ability and they can get this information by screening their applicants. Screening involves fixed costs and provides an imprecise signal about the ability of workers. The higher the investment into the screening technology, the better is the signal and the better is therefore the match between abilities of workers and skill requirements of tasks. Intuitively, firms that have a higher *ex ante* productivity install a better screening technology, so that heterogeneity of firms is reinforced by the endogenous investment into screening.

We use this framework to study the consequences of trade for welfare and underemployment, arising from the mismatch between workers and tasks. If only the best (most productive) firms self-select into exporting, trade exerts an asymmetric effect on the screening incentives of high- and low-productivity firms. High-productivity firms expand production due to exporting, and therefore find it attractive to install a better (more expensive) screening technology than in the closed economy. In contrast, low-productivity firms do not export and lose market share at home. In response, they lower their screening expenditures. Despite this asymmetry in firm-level adjustments to trade, we show that the average mismatch between worker-specific abilities and task-specific skill requirements unambiguously shrinks in the open economy. This points to a so far unexplored channel through which trade can improve the labor market outcome and stimulate welfare.

In an extension to our baseline model, we consider imperfections in the external labor market due to search frictions. Relying on a competitive search model with wage posting, we show that this modification does not alter our insights regarding the consequences of trade for the firm-internal allocation of workers to tasks. However, due to adjustments in involuntary unemployment, there is now a second channel through which trade affects economy-wide underemployment. Whether more or less workers find a job in the open economy is in general not clear and depends on the strength of selection of firms into exporting. If fixed costs of exporting are high relative to domestic fixed costs, selection into exporting is strong and in this case trade increases welfare and lowers underemployment due to a higher matching efficiency inside and outside the firm. In a calibration exercise, we rely on parameter estimates for French firms to quantify the relative importance of adjustments in the firm-internal and the firm-external labor market. We find that both adjustments are important channels for gains from trade to materialize. For instance, eliminating the ability of firms to screen their applicants and to adjust the quality of worker-task matches endogenously would lower gains from trade by almost 90 percent, whereas disregarding improvements in the outside labor market would lower gains from trade by 50 percent when relying on the preferred parametrization of our model.

To put it in broader perspective, one can interpret our analysis as an attempt to widen the picture of underemployment and to show that positive labor market consequences of trade need not only materialize due to a reduction in involuntary unemployment. Rather efficiency gains may be triggered by adjustments in the firm-internal organization of labor and according to our results these gains may indeed be sizable. Of course, more research is needed before one can draw a definite conclusion about how trade affects the way labor is used in modern production. We hope that the insights from our analysis encourage such research.

## 3.7 Appendix

### Existence and uniqueness of a maximum of $\pi(\omega)$

Let us first assume that system (3.8) and (3.9) has a solution, i.e. $\pi(\omega)$ has a stationary point $(l_0, \mu_0)$. Then, this stationary point is a strict local maximum if the Hessian matrix

$$H(\omega) = \begin{pmatrix} \pi_{ll}(\omega) & \pi_{l\mu}(\omega) \\ \pi_{\mu l}(\omega) & \pi_{\mu\mu}(\omega) \end{pmatrix} \tag{3.45}$$

of $\pi(\omega)$ is negative definite when evaluated at $(l_0, \mu_0)$. $H(\omega)$ is negative definite if $\pi_{ll}(\omega) < 0$ and $|H(\omega)| = \pi_{ll}(\omega)\pi_{\mu\mu}(\omega) - \pi_{l\mu}(\omega)^2 > 0$ hold. Twice differentiating $\pi(\omega)$ gives:

$$\pi_{ll}(\omega) = -\frac{\sigma-1}{\sigma^2}\frac{p(\omega)}{x(\omega)}\phi(\omega)^2\left[1+\mu(\omega)\right]^2 < 0, \tag{3.46}$$

$$\pi_{\mu\mu}(\omega) = -\frac{\sigma-1}{\sigma^2}\frac{p(\omega)}{x(\omega)}\phi(\omega)^2 l(\omega)^2 - \gamma(\gamma-1)\left[1+\mu(\omega)\right]^{\gamma-2}, \tag{3.47}$$

$$\pi_{l\mu}(\omega) = \pi_{\mu l}(\omega) = \left(\frac{\sigma-1}{\sigma}\right)^2 p(\omega)\phi(\omega) > 0. \tag{3.48}$$

With $r(\omega) = p(\omega)x(\omega)$ we can therefore compute

$$|H(\omega)| = \frac{\sigma-1}{\sigma^2}\frac{\phi(\omega)^2 p(\omega)}{x(\omega)}\left\{\frac{\sigma-1}{\sigma}(2-\sigma)r(\omega) + \gamma(\gamma-1)\left[1+\mu(\omega)\right]^{\gamma}\right\}. \tag{3.49}$$

Evaluating the latter at $(l_0, \mu_0)$, we can make use of (3.9) and set $r(\omega) = [\gamma\sigma/(\sigma-1)]\left[1+\mu(\omega)\right]^{\gamma}$. This implies

$$|H(\omega)| = \frac{(\sigma-1)^2}{\sigma^3}\phi(\omega)^2 p(\omega)^2\left[\gamma-(\sigma-1)\right] \tag{3.50}$$

and thus $|H(\omega)| >,=,< 0$ if $\gamma >,=,< \sigma-1$. Therefore, $\gamma > \sigma - 1$ gives a sufficient condition for a local maximum of $\pi(\omega)$ at stationary point $(l_0, \mu_0)$.

We now show that system (3.8), (3.9) has a unique interior solution for all active producers if we impose the additional parameter constraint $(1+f)(\sigma-1) > \gamma$. For this purpose, it is worth noting that for any given $\mu(\omega)$, Eq. (3.8) has a unique solution in $p(\omega)$ which is represented by (3.10). Accounting for (3.2) and substituting this constant markup pricing rule into (3.11), allows us to define a function

$$F\left(\mu(\omega)\right) \equiv \frac{Y}{M}\left(\frac{w}{\phi}\frac{\sigma}{\sigma-1}\right)^{1-\sigma} - \frac{\sigma\gamma}{\sigma-1}\left[1+\mu(\omega)\right]^{\gamma-\sigma+1}, \tag{3.51}$$

whose function value is equal to zero if first-order conditions (3.8) and (3.9) hold. It is easily confirmed that $F'(\cdot) < 0$ and $\lim_{\mu(\omega)\to\infty} F(\cdot) < 0$ hold if $\gamma > \sigma - 1$ is assumed. Hence, $F\big(\mu(\omega)\big) = 0$ has a unique solution in $\mu(\omega)$ if $F(0) > 0$. In view of constant markup pricing, operating profits are a constant fraction $1/\sigma$ of firm-level revenues $r(\omega) = p(\omega)x(\omega)$. Since the minimum possible fixed cost of production (without screening) equals $1+f$, firms are only willing to start production if $r(\omega) \geq \sigma(1+f)$. Accounting for (3.2) and (3.10), it follows that $r(\omega)$ is increasing in screening effort $\mu(\omega)$, so that

$$r(\omega) \geq \frac{Y}{M}\left(\frac{w}{\phi}\frac{\sigma}{\sigma-1}\right)^{1-\sigma}. \tag{3.52}$$

Putting together, it follows that $F(0) \geq \sigma(1+f) - \sigma\gamma/(\sigma-1)$ must hold for all active firms, rendering $(\sigma-1)(1+f) > \gamma$ sufficient for $F(0) > 0$.

Summing up, we can therefore conclude that the profit-maximization problem in Chapter 3.2 has a unique interior solution (for active producers) if $(\sigma-1)(1+f) > \gamma$ and $\gamma > \sigma - 1$ simultaneously hold. *QED*

## Derivation of Equation (3.15)

Aggregate revenues of all intermediate goods producers equal

$$R = M \int_{\phi^*}^{\infty} r(\phi) \frac{dG(\phi)}{1-G(\phi^*)} = Mr(\phi^*) \frac{\nu}{\nu-\xi} = M \frac{f\gamma\sigma}{\gamma-\sigma+1} \frac{\nu}{\nu-\xi}, \tag{3.53}$$

where (3.13) and (3.14) have been used. Dividing $R$ by $\sigma$ and subtracting fixed costs for operating the local distribution network, $Mf$, and for installing the screening technology,[19]

$$M \int_{\phi^*}^{\infty} [1+\mu(\phi)]^{\gamma} \frac{dG(\phi)}{1-G(\phi^*)} = M\left[1+\mu(\phi^*)\right]^{\gamma} \frac{\nu}{\nu-\xi} = M \frac{f(\sigma-1)}{\gamma-\sigma+1} \frac{\nu}{\nu-\xi}, \tag{3.54}$$

gives aggregate profits $\Pi = M\xi f/(\nu-\xi)$. Dividing $\Pi$ by $M$, we finally obtain (3.15). *QED*

## Derivation of Equation (3.18)

Total distance of worker-specific abilities and task-specific skill requirements can be calculated by multiplying the average distance of a firm by this firm's employment level and aggregating the resulting expression over all firms. This gives total underemployment:

$$\begin{aligned} U &= M \int_{\phi^*}^{\infty} \frac{l(\phi)}{3[1+\mu(\phi)]} \frac{dG(\phi)}{1-G(\phi^*)} = M \frac{l(\phi^*)}{3[1+\mu(\phi^*)]} \int_{\phi^*}^{\infty} \left(\frac{\phi}{\phi^*}\right)^{\frac{(\gamma-1)\xi}{\gamma}} \frac{dG(\phi)}{1-G(\phi^*)} \\ &= M \frac{l(\phi^*)}{3[1+\mu(\phi^*)]} \frac{\gamma\nu}{\gamma(\nu-\xi)+\xi}, \end{aligned} \tag{3.55}$$

where (3.2), (3.6), and (3.13) have been used. Dividing $U$ by economy-wide employment

$$L = M \int_{\phi^*}^{\infty} l(\phi) \frac{dG(\phi)}{1-G(\phi^*)} = Ml(\phi^*) \int_{\phi^*}^{\infty} \left(\frac{\phi}{\phi^*}\right)^{\xi} \frac{dG(\phi)}{1-G(\phi^*)} = Ml(\phi^*) \frac{\nu}{\nu-\xi}, \tag{3.56}$$

then gives *average* underemployment $u$ in (3.18). *QED*

## Derivation of Equation (3.24)

Total revenues in the open economy are given by

$$R = M \int_{\phi^*}^{\phi_x^*} r^n(\phi) \frac{dG(\phi)}{1-G(\phi^*)} + M(1+\tau^{1-\sigma}) \int_{\phi_x^*}^{\infty} r^e(\phi) \frac{dG(\phi)}{1-G(\phi^*)}. \tag{3.57}$$

Substituting (3.20) and accounting for (3.13), (3.14), we can calculate

$$R = M \frac{f\gamma\sigma}{\gamma-\sigma+1} \left(1 + \chi \frac{f_x}{f}\right) \frac{\nu}{\nu-\xi}. \tag{3.58}$$

[19] Again, Eqs. (3.13) and (3.14) are used for computing Eq. (3.54).

Dividing $R$ by $\sigma$ and subtracting fixed costs $Mf$, $M\chi f_x$, and

$$M\int_{\phi^*}^{\phi_x^*}[1+\mu^n(\phi)]^\gamma\frac{dG(\phi)}{1-G(\phi^*)}+M\int_{\phi_x^*}^{\infty}[1+\mu^e(\phi)]^\gamma\frac{dG(\phi)}{1-G(\phi^*)}$$
$$=M\frac{f(\sigma-1)}{\gamma-\sigma+1}\left(1+\chi\frac{f_x}{f}\right)\frac{\nu}{\nu-\xi},\qquad(3.59)$$

we get aggregate profits $\Pi=M\xi f(1+\chi f_x/f)/(\nu-\xi)$. Dividing $\Pi$ by $M$, finally gives (3.24). *QED*

## Derivation of Equation (3.28)

Total underemployment in the open economy is given by

$$U=M\int_{\phi^*}^{\phi_x^*}\frac{l^n(\phi)}{3[1+\mu^n(\phi)]}\frac{dG(\phi)}{1-G(\phi^*)}+M(1+\tau^{1-\sigma})\int_{\phi_x^*}^{\infty}\frac{l^e(\phi)}{3[1+\mu^e(\phi)]}\frac{dG(\phi)}{1-G(\phi^*)}.\qquad(3.60)$$

Using (3.2), (3.6), (3.13), and accounting for the definition of the exporter share, $\chi=(\phi_x^*/\phi^*)^{-\nu}$, we can compute

$$M\int_{\phi^*}^{\phi_x^*}\frac{l^n(\phi)}{3[1+\mu^n(\phi)]}\frac{dG(\phi)}{1-G(\phi^*)}=M\frac{l^n(\phi^*)}{3[1+\mu^n(\phi^*)]}\frac{\gamma\nu}{\gamma(\nu-\xi)+\xi}\left[1-\chi\left(\frac{\phi_x^*}{\phi^*}\right)^{\frac{(\gamma-1)\xi}{\gamma}}\right].\qquad(3.61)$$

Using in addition $l^e(\phi)/l^n(\phi)=\{[1+\mu^e(\phi)]\,/\,[1+\mu^n(\phi)]\}^{\sigma-1}$, according to (3.2) and (3.6), as well as $[1+\mu^e(\phi)]\,/\,[1+\mu^n(\phi)]=\left(1+\tau^{1-\sigma}\right)^{\xi/[\gamma(\sigma-1)]}$ from (3.20), we can further compute

$$M(1+\tau^{1-\sigma})\int_{\phi_x^*}^{\infty}\frac{l^e(\phi)}{3[1+\mu^e(\phi)]}\frac{dG(\phi)}{1-G(\phi^*)}$$
$$=M\frac{l^n(\phi^*)}{3[1+\mu^n(\phi^*)]}\frac{\gamma\nu}{\gamma(\nu-\xi)+\xi}\chi\left(\frac{\phi_x^*}{\phi^*}\right)^{\frac{(\gamma-1)\xi}{\gamma}}\left(1+\tau^{1-\sigma}\right)^{\frac{(\gamma-1)\xi}{\gamma(\sigma-1)}}.\qquad(3.62)$$

Substitution of (3.61) and (3.62) in (3.60) gives

$$U=M\frac{l^n(\phi^*)}{3[1+\mu^n(\phi^*)]}\frac{\gamma\nu}{\gamma(\nu-\xi)+\xi}\left\{1+\chi\left[\left(1+\tau^{1-\sigma}\right)^{\frac{(\gamma-1)\xi}{\gamma(\sigma-1)}}-1\right]\left(\frac{\phi_x^*}{\phi^*}\right)^{\frac{(\gamma-1)\xi}{\gamma}}\right\}.\qquad(3.63)$$

Using (3.22), (3.23), and accounting for the definition of $a(\tau)$ in (3.28), we obtain

$$U=M\frac{l^n(\phi^*)}{3[1+\mu^n(\phi^*)]}\frac{\gamma\nu}{\gamma(\nu-\xi)+\xi}\left[1+a(\tau)\chi^{1+\frac{\xi}{\nu\gamma}}\frac{f_x}{f}\right].\qquad(3.64)$$

Dividing $U$ by economy-wide employment

$$L=M\int_{\phi^*}^{\phi_x^*}l^n(\phi)\frac{dG(\phi)}{1-G(\phi^*)}+M(1+\tau^{1-\sigma})\int_{\phi_x^*}^{\infty}l^e(\phi)\frac{dG(\phi)}{1-G(\phi^*)}$$
$$=Ml^n(\phi^*)\frac{\nu}{\nu-\xi}\left(1+\chi\frac{f_x}{f}\right)\qquad(3.65)$$

and noting that $\mu^a(\phi_a^*)=\mu^n(\phi^*)$, finally gives $u$ in (3.28). *QED*

## The impact of marginal trade liberalization on underemployment $u$

Let us first define $\rho(\tau) \equiv \left(1+\tau^{1-\sigma}\right)^{\frac{\xi}{\sigma-1}}$, with $\rho'(\tau) < 0$. In view of (3.23) and (3.28), we can then rewrite $\chi$ and $a(\tau)$ in the following way:

$$\chi = \left(\frac{f}{f_x}\left(\rho(\tau)-1\right)\right)^{\frac{\nu}{\xi}} \qquad a(\tau) = \frac{\rho(\tau)^{\frac{\gamma-1}{\gamma}}-1}{\rho(\tau)-1}. \tag{3.66}$$

Totally differentiating $u$ with respect to $\tau$, therefore gives

$$\begin{aligned}\frac{du}{d\tau} = u^a \Bigg\{ & \frac{\chi f_x/f}{1+\chi f_x/f}\chi^{\frac{\xi}{\gamma\nu}}\frac{da(\tau)}{d\rho} \\ & + \frac{f_x/f}{(1+\chi f_x/f)^2}\left[\frac{\xi}{\gamma\nu}\chi^{\frac{\xi}{\gamma\nu}}a(\tau)\left(1+\chi\frac{f_x}{f}\right)+\chi^{\frac{\xi}{\gamma\nu}}a(\tau)-1\right]\frac{d\chi}{d\rho}\Bigg\}\rho'(\tau),\end{aligned} \tag{3.67}$$

according to (3.28). Substituting

$$\frac{da(\cdot)}{d\rho} = -\frac{1}{\rho(\tau)-1}\left(\frac{a(\tau)}{\gamma}-\frac{\gamma-1}{\gamma}\frac{1-\rho(\tau)^{-\frac{1}{\gamma}}}{\rho(\tau)-1}\right), \qquad \frac{d\chi}{d\rho} = \frac{\nu}{\xi}\frac{\chi}{\rho(\tau)-1}, \tag{3.68}$$

we can calculate

$$\frac{du}{d\tau} = \frac{\Omega}{\rho(\tau)-1}\frac{\chi f_x/f}{(1+\chi f_x/f)^2}\rho'(\tau), \tag{3.69}$$

with

$$\Omega \equiv \chi^{\frac{\xi}{\gamma\nu}}\left(1+\chi\frac{f_x}{f}\right)\frac{\gamma-1}{\gamma}\frac{1-\rho(\tau)^{-\frac{1}{\gamma}}}{\rho(\tau)-1}+\frac{\nu}{\xi}\left(\chi^{\frac{\xi}{\gamma\nu}}a(\tau)-1\right). \tag{3.70}$$

Noting that $1+\chi f_x/f = 1+\chi^{1-\xi/\nu}\left(\rho(\tau)-1\right)$ holds, according to (3.66), it is easily confirmed that $1+\chi f_x/f < \rho(\tau)$ for any $\chi < 1$. This implies

$$\begin{aligned}\Omega &< \chi^{\frac{\xi}{\gamma\nu}}\frac{\gamma-1}{\gamma}\frac{\rho(\tau)-\rho(\tau)^{\frac{\gamma-1}{\gamma}}}{\rho(\tau)-1}+\frac{\nu}{\xi}\left(\chi^{\frac{\xi}{\gamma\nu}}a(\tau)-1\right) \\ &= -\left(\frac{\nu}{\xi}-\frac{\gamma-1}{\gamma}\right)\chi^{\frac{\xi}{\gamma\nu}}\left[1-a(\tau)\right]-\frac{\nu}{\xi}\left(1-\chi^{\frac{\xi}{\nu\gamma}}\right).\end{aligned}$$

Since the right-hand side of this inequality is negative, we can conclude that $\Omega < 0$ and, in view of $\rho'(\tau) < 0$, $du/d\tau > 0$ must hold. This confirms that a marginal decline in $\tau$ unambiguously lowers underemployment $u$ in our setting and thus completes the proof. *QED*

## Source code for the calibration exercise in Chapter 3.5

The calibration exercise has been executed in *Mathematica*. In the following we offer the source code to derive the reported values from Table 3.1. At first, we define $\xi \equiv \gamma(\sigma-1)/(\gamma-\sigma+1)$ and set the parameter values for $\sigma = 6.7$ and $\nu = 7$ ($\nu = 9$ or $\nu = 11$).

```
ξ=γ(σ-1)/(γ-σ+1);
σ=6.7;
ν=7;
```

In a next step, we set $\xi/\nu = 0.87$ and use the FindRoot command to solve for $\gamma$. With $\gamma$ at hand, we can compute the corresponding $\xi$-level. We use $\gamma 1$ and $\xi 1$ to refer to the specific values of $\gamma$ and $\xi$ thus calculated. We also check whether the parameter restrictions from the main text are fulfilled.

```
a=FindRoot[ξ/ν=0.87,{γ,100}];
γ1=γ/.a
ξ1=ξ/.a
If[γ1<=(ν(σ-1))/(ν-σ+1), Print["Error:  γ to low 1!"]]
If[γ1<=σ-1, Print["Error:  γ to low 2!"]]
If[ν<ξ1, Print["Error:  ν to low 1!"]]
If[ν<σ-1, Print["Error:  ν to low 2!"]]
```

To simplify notation in the calibration exercise, we set $f = 1$ and accordingly use $f_x$ to measure the fixed cost ratio $f_x/f$. To compute this fixed cost ratio, we consider $\tau = 1.5$, as suggested by McGowan and Milner (2013) and Novy (2013), and set the share of exporters in (3.23) at the value reported by Eaton, Kortum, and Kramarz (2011). We use $\chi f$ to refer to this specific value of $\chi$ and thus have $\chi f = 0.15$.[20] Applying the FindRoot command gives $f_x$, with $fx1$ being used to refer to the thus calculated value of the exporter fixed cost.

```
τ=1.5;
χ=(fx^(-1)(1+τ^(1-σ))^(ξ/(σ-1))-1)^(ν/ξ);
χ1=χ/.{γ->γ1};
χf=N[34558/230423];
b=FindRoot[χ1==χf, {fx,0.5}];
fx1=fx/.b
```

To compute the impact of trade on wages, employment, welfare, and the average mismatch, we can use Eqs. (3.28) and (3.39)-(3.41). Considering the computed values of the fixed cost ratio, $\gamma$, and $\xi$, setting $\zeta = 0.5$ and accounting for $\chi f = 0.15$, we can to compute the trade effects, reported in Table 3.1.

```
ζ=0.5;
Δw=((1+χ*fx)/(1+χ))^(1/(σ-1))(1+χ*fx)^(1/ν);
Δw1=Δw/.{χ->χf, fx->fx1};
aτ=((1+τ^(1-σ))^(((γ-1)ξ1)/(γ(σ-1))))/((1+τ^(1-σ))^((ξ1)/(σ-1))-1);
Δu=(1+aτ*χ^(1+ξ1/(ν*γ))*fx)/(1+χ*fx);
Δu1=Δu/.{χ->χf, fx->fx1, γ->γ1};
ΔEmployment(Δw1)^(ζ/(1-ζ));
ΔWelfare=ΔEmployment^(1/ζ);
Print["Welfare effects:  ", Round[100*(ΔWelfare-1),0.01]];
Print["Employment effects:  ", Round[100*(ΔEmployment-1),0.01]];
Print["Average mismatch effects:  ", Round[100*(Δu1-1),0.01]]
```

In the following, we offer the source code for computing the trade effects in the limiting case of $\gamma \to \infty$, as reported in Chapter 3.5. Thereby, we consider the preferred parametrization of our model and thus set $\nu = 11$ and $\sigma = 6.7$ to compute $\xi$. We also check whether the parameter constraints are fulfilled.

[20] More specifically, Eaton, Kortum, and Kramarz (2011) report that in their sample of 230423 French manufacturing firms 34558 firms export.

```
σ=6.7;
ν=11;
ξ=γ(σ-1)/(γ-σ+1);
ξ1=Limit[ξ, γ->Infinity];
If[ν<ξ1, Print["Error:  ν too low!"]]
```

Using the calculated fixed cost ratio from table 3.1 together with $\tau = 1.5$, we can compute the exporter share if $\xi = \xi 1$:

```
fx=0.983287’;
τ=1.5;
χ=(fx^(-1)(1+τ^(1-σ))^(ξ1/(σ-1))-1)^(ν/ξ1);
Print["Export share:  ", Round[χ,0.01]]
```

With $\zeta = 0.5$, we can finally use Eqs. (3.39)-(3.41) to compute the impact of trade on welfare and employment for the limiting case $\gamma \to \infty$.

```
ζ=0.5;
Δw=((1+χ*fx)/(1+χ))^(1/(σ-1))(1+χ*fx)^(1/ν);
ΔEmployment(Δw1)^(ζ/(1-ζ));
ΔWelfare=ΔEmployment^(1/ζ);
Print["Welfare effects:  ", Round[100*(ΔWelfare-1),0.01]];
Print["Employment effects:  ", Round[100*(ΔEmployment-1),0.01]];
```

This completes the source code for the calibration exercise.

# Chapter 4

# Trade and the Firm-internal Assignment of Skills to Tasks

## 4.1 Introduction

The organization of production within firms is a key determinant of firm performance. The ability to allocate scarce resources within the boundaries of firms efficiently, is essential for firms to compete in modern economic life.[1] When it comes to the organization of labor within firms, this topic is discussed in the literature on personnel economics. However, in the trade literature, firms were treated as a black box over centuries. This perspective has changed over the last few years, where recent contributions have provided new insights, how trade shapes the internal organization of national and multinational firms. Thereby, the focus has been on corporate hierarchies. For instance, Caliendo and Rossi-Hansberg (2012) highlight that a firm's productivity depends on how production is organized, and this organization changes in the process of globalization.[2] This chapter takes a different approach and introduces the idea of a task-based production process into a framework of international trade. Of course, with the production process consisting of different tasks, firms face new problems that are ignored in the existing literature. If the set of tasks in a firm differ in complexity and workers differ in their abilities to perform these tasks, the organization of workers to specific tasks inside the firm becomes relevant.[3] Modeling the assignment of workers to tasks and a discussion on how this assignment changes in an open economy is in the center of this chapter's interest.

For this purpose, I introduce a task based production process along the lines of Acemoglu and Autor (2011) into a standard trade model with monopolistic competition among heterogeneous firms, as in Melitz (2003). In this framework, firm output is assembled from a continuum of tasks that differ in complexity. For the performance of tasks, firms can hire low-skilled or high-skilled workers, while a higher skill level causes a comparative advantage in the performance of more complex tasks. How firms assign skills to tasks depends on the comparative advantage of high-skilled workers and their skill premium. By altering the range of tasks performed by

[1] In a recent paper by Giroud and Mueller (2012), it is shown that firm-level productivity increase, due to the efficient resource reallocation within firms.

[2] See also Marin and Verdier (2008b, 2012).

[3] Clearly, there exists a large theoretical literature, that discusses how heterogeneous workers sort to different industries, how they match with other workers, firms, and with other factors of production and how trade affects this matching and the wage distribution (see Grossman, 2013, for a recent survey of this literature).

high-skilled workers, firms do not only affect their labor costs but also their productivity. To determine the optimal skill range and to manage the firm and organize the complex production process, firms need a fixed input of high-skilled workers. In a benchmark model, I assume that labor markets are perfectly competitive. After solving for the general equilibrium in a closed economy, I analyze changes in factor endowments, which can be interpreted as migration problem. The main insights from this analysis are that an increase in the supply of low-skilled workers raises the range of tasks performed by this skill type, which triggers a decline in the productivity of firms. While low-skilled workers lose due to a reduction in their real wage, high-skilled workers gain in absolute and relative terms, as they see their real wage and skill premium rising. Even though the mass of firms increases, overall welfare effects are ambiguous due to the decline in productivity. In the case of high-skilled migration, firm productivity increases as firms use this skill type for the performance of a broader range of tasks. While low-skilled workers experience an increase in their income, the impact on high-skilled wages are less clear-cut and depend on model parameters. As firm number and productivity increases, overall welfare effects are positive.

In a second step, I consider a minimum wage for the group of low-skilled workers, to account for the empirical fact that unemployment is persistent especially among this group of workers. This reduces welfare relative to a benchmark with fully flexible wages and generates unemployment of low-skilled workers. Moreover, the introduction of a minimum wage lowers per-capita income of high-skilled and low-skilled workers and increase the relative income of high-skilled workers. Similar to Brecher (1974), in such an economy migration of low-skilled workers is fully absorbed by a pari passu increase in unemployment and a reduction in welfare but leaves all other variables unaffected. In contrast to a situation with fully flexible wages, migration of high-skilled workers reduces the range of tasks performed by this group of workers, and thus firm-level productivity, due to a magnification effect at the entrance of firms. Moreover, high-skilled workers gain in absolute and relative terms, and the unemployment rate for low-skilled workers goes down, implying that welfare must increase.

To shed light on the assignment of skills to tasks and a firm's production process if the country under consideration opens up to trade, I discuss trade between two fully symmetric countries. Similar to Krugman (1979), in a situation with fully flexible wages, trade only increases the real wage for each skill type and aggregate welfare, while leaving all other variables unaffected. However, when low-skilled wages are fixed by the government, trade also affects a firm's production process. Due to a standard division of labor effect, demand for firms in each country is higher in the open economy. This stimulates aggregate labor demand, and, as low-skilled wages are fixed, the skill premium in each country. Firms respond to this change in relative factor prices and assign low-skilled workers to a broader range of tasks. This skill downgrading reduces productivity of firms and accounts for a so far unexplored channel, through which trade affects local production practices. However, as trade reduces high-skilled task production, more firms can enter the market, implying that welfare effects are positive.

After shedding light on how trade between two countries affects the task based production process, I use the framework to discuss how changes in a countries labor market institutions spill over to the partner country. Starting from an equilibrium with trade between two minimum wage economies, an increase in one country's minimum wage also affects the assignment of skills to tasks in the partner country. Due to a reduction in aggregate labor demand which reduces the skill premium, firms produce a broader share of tasks with high-skilled workers and therefore become more productive. However, beside these positive productivity spillovers, firm number and per-capita income for high-skilled workers are reduced, while low-skilled workers face a higher unemployment rate, which, in sum, are instrumental for a decline in welfare.

Accounting for differences in factor endowments has no impact on the insights from an open economy scenario with fully flexible wages. However, if both countries set a minimum wage for the group of low-skilled workers, high-skilled migration in one country increases the mass of firms and the range of tasks performed by low-skilled workers in the partner country, and reduces firm-level productivity, there. Low-skilled workers face a lower unemployment rate, while high-skilled workers face an increase in the real wage, but see their relative income shrinking, and welfare in the partner country rises.

By shedding light how trade affects the firm-internal labor market, this chapter is related to a growing literature that analyzes how globalization shapes the organization of production. In this chapter, changes in the assignment of workers with different skills to tasks with differing complexity affects a firm's productivity level. This is a novel mechanism that differentiates this model from other trade models with a task-based production function. For instance, recent contributions to the literature on offshoring builds upon Grossman and Rossi-Hansberg (2008).[4] In the Grossman and Rossi-Hansberg (2008) framework, production also consists of a continuum of low-skilled and high-skilled tasks. However, their model provides a perfect mapping between skills and tasks, as the set of tasks for each skill type is exogenous: low-skilled workers are restricted to work in low-skill tasks and high-skilled workers are only assigned to high-skill tasks. In my framework, things are more sophisticated, because each skill type can in principle perform the whole range of tasks within a firm and the assignment decision depends on the relative performance of low-skilled and high-skilled workers in task production and on the respective factor costs. The endogenous assignment of workers with differing abilities to tasks with differing skill requirements is also discussed in a recent paper by Egger and Koch (2013). While the production side is similar to my framework, they differ with respect to heterogeneity in the workforce. In the Egger and Koch (2013) framework, workers are horizontally differentiated, implying that workers differ in their ability to perform certain tasks because their human capital is occupation-specific. Moreover, firms have to invest into a screening mechanism to get some information about the hidden task-specific abilities of workers. By increasing the screening intensity, firms can improve the matching of workers to tasks and thereby firm productivity. In the present model, firms have perfect information about the abilities of workers and the focus is on how firms assign low-skilled and high-skilled workers to tasks with differing complexity. Thereby, high-skilled workers have an absolute productivity advantage in the performance of all tasks. However, they are also more expensive, and hence firms find it attractive to assign high-skilled workers only to tasks with high complexity, since their comparative advantage is declining with less complexity. The range of tasks performed by high-skilled workers determines firm-productivity, and hence firms with higher skill intensity end up being more productive. An alternative mechanism, that relates firm productivity to the organization of workers in the production process is discussed by Caliendo and Rossi-Hansberg (2012). In their model it is the hierarchy structure within firms, i.e. the number of layers of management and the knowledge and span of control of each agent that is instrumental for firm performance.

By allowing for changes in the firm-internal assignment of workers to tasks, the chapter also contributes to a vivid discussion on how trade affects productivity. The seminal paper by Melitz (2003) proposes an increase in aggregate productivity due to a change in the composition of active producers, while leaving firm-level productivity unaffected. Bustos (2011) extends the Melitz-framework by allowing firms to invest into their technology. Since exporters gain market size in the open economy, they find it more attractive to invest into their technology, and hence end up having a higher productivity. In Helpman, Itskhoki, and Redding (2010), exporters extend their screening investments and thus have a better workforce composition and therefore

[4] See, for instance, Kohler and Wrona (2011), Benz (2012) or Grossman and Rossi-Hansberg (2012).

higher productivity than in the closed economy. In Egger and Koch (2013) the expansion of screening leaves the workforce composition unaffected but improves the assignment of workers to tasks with positive productivity effects. Interestingly, empirical evidence at the firm-level is not conclusive.[5] My model provides a reasoning for this. Because trade expand demand for high-skilled workers as a fixed input in the production process, it leaves less high-skilled resources for task production. This worsens the skill composition with correspondent consequences for firm-level productivity.[6] This effect, however, does only exist if labor markets are not perfectly competitive, with labor market imperfection being modeled by means of a binding minimum wage.

By introducing a minimum wage for low-skilled workers, this chapter is related to a sizable literature that accounts for different forms of labor market imperfections in the Melitz (2003)-framework.[7] One feature in these studies is that the labor market imperfection has no impact on the productivity of a specific firm but affects the average productivity of all active producers due to changes in the composition of firms. For instance, in Egger and Kreickemeier (2009), a more important rent sharing motive in workers' fair wage preferences reduces labor costs for low productive firms relative to their more productive competitors, because wages in high productive firms increase disproportionately with the rent sharing motive. This implies, somewhat counterintuitive, that profits for the cutoff firm increase. With more unproductive firms being able to survive in the market, the average productivity falls. A different mechanism is studied in Egger, Egger, and Markusen (2012). In their paper, a more severe labor market imperfection increases the common wage and the marginal production costs proportionally. This forces the least productive firms to exit and thus increases average productivity, because the composition of firms improves. In my model, productivity effects arise from different wage setting institutions for low-skilled and high-skilled workers which affect the firm-internal assignment of skills to tasks and thus a firm's productivity. Hence, the labor market imperfection leads to a reallocation of workers within firms, while in existing studies on heterogeneous firms, labor is reallocated between firms.

Allowing for differences in the prevailing labor market institutions between two trading partners, the chapter is also related to a literature that discusses labor market linkages in open economies. Starting with the seminal work by Davis (1998), several authors have discussed how labor market imperfections in one country spill over to foreign markets.[8] In a recent paper, Egger, Egger, and Markusen (2012) build upon a similar framework as the one considered in this chapter. In particular, they also consider monopolistic competition between heterogeneous firms. However, in contrast to the approach taken here, production in Egger, Egger, and Markusen (2012) only consists of a single task. They furthermore differ in the underlying entry mechanism, by assuming an exogenous mass of potential entrants. This modification turns out to be instrumental for their results. In particular, the exogenous pool of potential entrants establishes a link between the minimum wage and the cutoff productivity of the marginal firm and implies that if two countries with differing minimum wages engage in trade, they end up

[5] Wagner (2007) provides a survey on the link between exporters and productivity on the evidence from firm level data. After studding 45 microeconometric studies he concludes that "exporting does not necessarily improve productivity" (p.1).

[6] This effect is well in line with empirical evidence. For instance, Harrigan and Reshef (2011) argue the "empirical studies have failed to find large effects of trade liberalization on firm-level or plant-level skill upgrading" (p.3).

[7] Prominent examples are Davidson, Matusz, and Shevchenko (2008); Davis and Harrigan (2011); Egger and Kreickemeier (2009, 2012); Egger, Egger, and Markusen (2012); Felbermayr, Prat, and Schmerer (2011); Helpman and Itskhoki (2010); Helpman, Itskhoki, and Redding (2010).

[8] Prominent examples are Oslington (2002), Kreickemeier and Nelson (2006), Meckl (2006) or Felbermayr, Larch, and Lechthaler (2013).

with differing compositions of local producers. In the present chapter, firm entry is modeled along the line of Melitz (2003), and this renders the cutoff productivity level independent of the prevailing minimum wage. Nonetheless, despite differences in the level, minimum wages can be binding in both countries, because the endogenous assignment of skills to tasks allows to absorb for differences in local labor market institutions. Taking stock, the model presented in this chapter suggests that differences in labor market institutions lead to different skill intensities and firm productivities, but leave the composition of producers unaffected.[9]

The remainder of the chapter is organized as follows. In Chapter 4.2, I introduce the model and characterize the equilibrium outcome in the closed economy. I start with a benchmark model, in which wages are fully flexible and then consider a model variant with a binding minimum wage. Furthermore, I conduct two comparative static experiments and analyze how changes in the endowment with low-skilled and high-skilled workers affect the equilibrium outcome in the closed economy under the two labor market regimes. In Chapter 4.3, I provide insights into the impact of trade on the firm-internal assignment of skills to tasks when labor markets are perfectly competitive or low-skilled wages are set by the government. In Chapter 4.4, I discuss how labor markets are linked in open economies and analyze to what extent previous insights from my analysis depend on the assumption of symmetric countries. Chapter 4.5 concludes with a brief summary of the most important results.

## 4.2 The closed economy

### 4.2.1 Model structure and firm-level analysis

Consider an economy that is populated by an exogenous mass of $L$ low-skilled and $H$ high-skilled workers and hosts two sectors of production: a final goods industry that assembles intermediates, and an intermediates goods industry, which employs labor for performing different tasks. The final good $Y$ is homogeneous and produced under perfect competition, according to a constant-elasticity-of-substitution (CES) production function (see Matusz, 1996):

$$Y = \left[\int_{\omega\in\Omega} x(\omega)^{\frac{\sigma-1}{\sigma}} d\omega\right]^{\frac{\sigma}{\sigma-1}}, \tag{4.1}$$

where $x(\omega)$ denotes the quantity of intermediate variant $\omega$ used in the production of $Y$, set $\Omega$ represents the mass of available intermediate goods with Lebesgue measure $M$, and $\sigma > 1$ denotes the (constant) elasticity of substitution between variants of the intermediate.

Choosing the final good as numéraire, profits in the final goods industry are $Y - \int_{\omega\in\Omega} p(\omega)x(\omega)d\omega$, where $p(\omega)$ denotes the price of variety $\omega$. Maximizing these profits with respect to $x(\omega)$ gives intermediate goods demand[10]

$$x(\omega) = Yp(\omega)^{-\sigma}. \tag{4.2}$$

Intermediate goods producers compete with rival firms in a monopolistically competitive environment. Each firm produces a unique variety, by combining a continuum of tasks represented by the unit interval. I follow Acemoglu and Autor (2011) and use a simple Cobb-Douglas

[9]This mechanism would also be effective in a Krugman (1979)-type model with homogeneous producers. However, in line with the recent literature in international economics and to contrast my results with Egger, Egger, and Markusen (2012), I prefer a setting with heterogeneous firms along the lines of Melitz (2003), where firms differ in terms of their (exogenous) productivity.

[10]Due to the choice of the numéraire, the CES price index corresponding to $Y$, $P = [\int_{\omega\in\Omega} p(\omega)^{1-\sigma} d\omega]^{1/(1-\sigma)}$, is equal to one.

function to formalize the assembly of tasks in the production of intermediates:

$$x(\omega) = \phi(\omega) \exp \left[ \int_0^1 \ln x(\omega, i) di \right], \tag{4.3}$$

where $\phi(\omega)$ is a firm's baseline productivity that measures the efficiency to coordinate and bundle tasks and $x(\omega, i)$ is the production level of task $i$ in firm $\omega$. Tasks are performed by low-skilled and high-skilled workers, $l(\omega, i)$ and $h(\omega, i)$ respectively, who are employed in a linear-homogeneous production function of the form[11]

$$x(\omega, i) = \alpha_l(i) l(\omega, i) + \alpha_h(i) h(\omega, i), \tag{4.4}$$

where $\alpha_l(i)$ and $\alpha_h(i)$ are the labor productivities of the two skill types, when performing task $i$. The task level production function in (4.4) implies that low-skilled and high-skilled workers are substitutes in the performance of tasks. However, the productivity of workers in performing a specific task differs, because workers differ in their abilities, while tasks differ in their skill requirements. To capture performance (i.e. productivity) differences across tasks between the two skill groups in a simple way, I impose the following assumption on absolute and comparative advantages in the performance of tasks:

**Assumption 1** *Denoting the labor productivity ratio between high- and low-skilled workers in tasks $i$ by $\alpha(i) \equiv \alpha_h(i)/\alpha_l(i)$, it is assumed that $\alpha(i)$ is a continuously differentiable, strictly increasing and convex function of $i$, i.e. $\alpha'(i) > 0$, $\alpha''(i) \geq 0$, with $\alpha(0) = 1$. To implement these properties in a tractable way, I consider $\alpha_l(i) = 1$ and $\alpha_h(i) = \alpha(i) = \exp[i]$ for all $i \in [0, 1]$.*

This assumption captures the idea that tasks can be ordered according to their complexity, with a higher index referring to higher complexity. A high-skilled worker that is assigned to the least complex task, is as productive as her low-skilled coworker, since her specific skills are not required for performing the respective task. Things are different in the case of a more complex task, where the higher skill level causes an absolute productivity advantage over low-skilled coworkers. Changes in the assignment of workers of different skill levels to the different tasks affect a firm's productivity level. This is a novel mechanism that plays a crucial role in the subsequent analysis and differentiates this model from other trade models with a task-based production function.

Intermediate goods producers maximize their profits according to a two-stage optimization problem. In a first step, firms assign skills to tasks and thereby determine the range of tasks performed by low-skilled and high-skilled workers, respectively. In a second step, they choose task-level output, which is equivalent to determining the task-level employment for a given skill assignment. In the subsequent analysis, I solve this two-stage problem through backward induction.

For a given assignment of workers to tasks, intermediate goods producers set task-level output $x(\omega, i)$, to maximize their profits

$$\pi(\omega) = p(\omega) x(\omega) - \int_0^1 x(\omega, i) c_k(\omega, i) di - f w_h, \tag{4.5}$$

subject to (4.2) and (4.3), where $c_k(\omega, i)$ denotes the unit costs of a firm $\omega$ performing task $i$ with the preassigned skill type $k = l, h$ and $f$ measures the fixed input of high-skilled labor

[11] Acemoglu and Autor (2011) additionally account for medium-skilled workers in their model, since their main motivation is to analyze the observed increase of employment in high-skilled and low-skilled occupations relative to middle skilled occupations, which they call "job polarization". To keep the model tractable, I abstract from this third skill type, here.

that is required to manage the firm and organize the production process.[12] With a Cobb-Douglas production function, this gives the standard result of a constant cost share for each task. Furthermore, in the special case of each task entering the production function symmetrically, cost shares for all tasks are the same. To be more specific, substitution of (4.2) into the first-order condition $\partial\pi(\omega)/\partial x(\omega, i) = 0$ gives

$$\frac{\sigma - 1}{\sigma} p(\omega)x(\omega) = x(\omega, i)c_k(\omega, i). \tag{4.6}$$

Integrating over the unit interval, shows that prices are set as a constant markup $\sigma/(\sigma - 1)$ over variable unit costs $C(\omega)/x(\omega)$: $p(\omega) = [\sigma C(\omega)]/[(\sigma - 1)x(\omega)]$, where $C(\omega) \equiv \int_0^1 x(\omega, i)c_k(\omega, i)di$ are a firm's total variable labor costs.

With these insights at hand, I am now equipped to determine the optimal range of tasks performed by a specific skill type. For this purpose, I focus on the case of interior solutions and assume that both skill groups are used for the production of intermediates.[13] Since tasks are ordered according to their complexity, I can then define a unique threshold task $z(\omega) \in (0, 1)$, for which the firm is indifferent between hiring low-skilled or high-skilled workers, at prevailing relative wages $s \equiv w_h/w_l$. To put it formally, the unit costs $c_k(\omega, z(\omega))$ of a firm $\omega$ performing task $z(\omega)$ are the same irrespective of the assigned skill type $k = l, h$. This implies $c_l(\omega, z(\omega)) = c_h(\omega, z(\omega))$ or, equivalently

$$w_l = \frac{w_h}{\alpha_h(z(\omega))} \tag{4.7}$$

and establishes $s \equiv w_h/w_l = \alpha(z)$. Due to the absolute advantage of high-skilled workers in the performance of all tasks, the existence of an interior solution, $z(\omega) \in (0, 1)$, requires a skill premium, i.e. $s > 1$. Furthermore, due to relative advantage of high-skilled workers in performing more complex tasks, it follows that low-skilled workers will be assigned to all tasks $i < z(\omega)$, while high-skilled workers will be assigned to all tasks $i \geq z(\omega)$.[14] Notably, since all firms are price takers in the labor market and pay the same $w_h$, $w_l$, the threshold task $z(\omega)$ is the same for all intermediate goods producers, and hence I can write $z(\omega) \equiv z$ for all $\omega$. With the threshold task at hand, I can combine Eqs. (4.3) and (4.4) to rewrite firm output as

$$x(\omega) = \phi(\omega)\varphi(z) \exp\left[\int_0^z \ln l(\omega, i)di + \int_z^1 \ln h(\omega, i)di\right] \tag{4.8}$$

where $\varphi(z) \equiv \exp\left[\int_0^z \ln \alpha_l(i)di + \int_z^1 \ln \alpha_h(i)di\right] = \exp[(1 - z^2)/2]$. According to (4.8), firm productivity consists of two parts: an exogenous baseline productivity $\phi(\omega)$ and the endogenous productivity term $\varphi(z)$, which varies with the assignment of skills to tasks, and thus is a function of threshold task $z$. From $\varphi'(z) = -\varphi(z) \ln \alpha(z) = -z\varphi(z)$ it follows that firms can raise their productivity when performing a larger share of tasks with high-skilled workers. However, if $s > 1$, this comes at the cost of higher wages and is therefore not necessarily beneficial.

A direct implication of the identical cost share (see above) is that the amount of workers of a specific skill type employed for performing tasks is the same for all tasks performed by

[12] The assumption that high-skilled workers are needed to manage the firm and organize the production process is in line with the literature focusing on the internal organization of firms in economies with heterogeneous workers (see, for instance, Marin and Verdier, 2008b, 2012).

[13] Below, I will discuss a parameter constraint that needs to be fulfilled in order for such an interior solution to materialize.

[14] For convenience, it is assumed that firms hire high-skilled workers for performing task $z(\omega)$.

workers of this skill type. This can be seen from substitution of (4.4) and $c_k(\omega, i) = w_k/\alpha_k(i)$, with $k = l$ if $i < z$ and $k = h$ if $i \geq z$, into (4.6), which gives $w_l l(\omega, i) = w_l l(\omega)$ for all $i < z$ and $w_h h(\omega, i) = w_h h(\omega)$ for all $i \geq z$. Similarly, it follows from (4.4), (4.6) and (4.7) that $w_l l(\omega) = w_h h(\omega)$. This implies

$$s = \frac{l(\omega)}{h(\omega)} = \frac{1-z}{z}\frac{L(\omega)}{H(\omega)}, \tag{4.9}$$

where $L(\omega) = \int_0^z l(\omega, i)di = zl(\omega)$ and $H(\omega) = \int_z^1 h(\omega, i)di = (1-z)h(\omega)$ are firm $\omega$'s total low-skilled and high-skilled variable labor input, respectively. Accordingly, a firm's skill intensity is given by $H(\omega)/L(\omega) = (1-z)/[z\alpha(z)]$ and thus decreasing in $z$. Putting together, I can thus write a firm's total variable labor costs as $C(\omega) = [wL(\omega)/H(\omega) + w_h]H(\omega)$, while this firm's output is given by $x(\omega) = \phi(\omega)\varphi(z)\{[(1-z)/z]L(\omega)/H(\omega)\}^z h(\omega)$. Substitution of (4.9), then gives me for the variable unit cost of this firm: $C(\omega)/x(\omega) = w_l^z w_h^{1-z}/[\phi(\omega)\varphi(z)]$, which is equal to the marginal cost of the respective producer. Constant markup pricing therefore implies

$$p(\omega) = \frac{\sigma}{\sigma-1}\frac{w_l^z w_h^{1-z}}{\phi(\omega)\varphi(z)}. \tag{4.10}$$

Noting that revenues of firm $\omega$ are given by $r(\omega) = p(\omega)x(\omega)$ and taking into account that $w_l$, $w_h$ and $\varphi(z)$ are the same for all producers, it follows from (4.2) and (4.10) that the revenue ratio of two firms 1 and 2 with productivity levels $\phi(\omega_1)$, $\phi(\omega_2)$ is given by $r(\omega_1)/r(\omega_2) = [\phi(\omega_1)/\phi(\omega_2)]^{\sigma-1}$. Hence, relative firm performance is fully characterized by the baseline productivity ratio. I can thus skip firm index $\omega$ from now on, and instead refer to firms by their productivity levels.

Regarding firm entry, I follow the literature on heterogeneous firms along the lines of Melitz (2003) – with the mere difference that I consider a static model variant along the lines of Helpman and Itskhoki (2010) and Helpman, Itskhoki, and Redding (2010) – and assume that the baseline productivity is drawn by firms in a lottery from the common Pareto distribution, $G(\phi) = 1 - \phi^{-k}$.[15] The participation fee for the lottery is $f_e w_h$ and this fee gives a firm a single productivity draw. Having revealed their productivity, producers decide upon setting up a plant and starting production by making the additional investment of $f$ units of high-skilled labor (see above). With revenues (and thus profits) increasing in baseline productivity, I can identify a cutoff productivity level, $\phi^*$, which separates active firms with $\phi \geq \phi^*$ from inactive ones with $\phi < \phi^*$. The profits from production of a firm with cutoff productivity $\phi^*$ are equal to zero by definition and I can thus characterize the marginal firm with cutoff productivity level $\phi^*$ by means of a zero profit condition $\pi(\phi^*) = 0$. This zero profit condition is usually referred to by the term zero-cutoff profit condition. In view of a Pareto distribution of baseline productivity levels, there is a proportional link between revenues of the marginal producer and average revenues of all active producers. As outlined in the appendix, this link can be used to establish the modified zero-cutoff-profit condition

$$\bar{\pi} = \frac{fw_h(\sigma-1)}{k-\sigma+1}, \tag{4.11}$$

where $k > \sigma - 1$ is required for a positive, finite value of $\bar{\pi}$. In equilibrium the costs of entering the productivity lottery, $f_e w_h$, must be equal to the expected profit of doing so, $\bar{\pi}(1 - G(\phi^*))$.

[15] Corcos, Del Gatto, Mion, and Ottaviano (2012) provide evidence for the Pareto distribution, using firm level data for European countries.

This establishes the free entry condition

$$\bar{\pi} = f_e w_h (\phi^*)^k. \tag{4.12}$$

Combining (4.11) and (4.12), I can explicitly solve for cutoff productivity level $\phi^*$:

$$\phi^* = \left( \frac{f}{f_e} \frac{\sigma - 1}{k - \sigma + 1} \right)^{1/k}. \tag{4.13}$$

Eqs. (4.11) and (4.13) are the key firm-level variables, which are also informative for economy-wide variables. In particular, with $\phi^*$ at hand, I can calculate the productivity average $\tilde{\phi} \equiv [k/(k-\sigma+1)]^{1/(\sigma-1)}\phi^*$,[16] which is useful because key aggregate variables in this model of heterogeneous firms are the same as they would be in an otherwise identical model of homogeneous firms with productivity $\tilde{\phi}$: $R = Mr(\tilde{\phi})$, $\Pi = M\pi(\tilde{\phi})$, and, $Y = M^{\sigma/(\sigma-1)}x(\tilde{\phi})$ and $P = M^{1/(1-\sigma)}p(\tilde{\phi})$. With these insights at hand, I can now turn to study the general equilibrium outcome in my model.

### 4.2.2 General equilibrium with perfect labor markets

To solve for the general equilibrium outcome in the closed economy, I have to specify how wages are determined. I start with a benchmark scenario, in which wages of low-skilled and high-skilled workers are flexible and determined in perfectly competitive markets. Using the adding up condition, which simply says that adding up employment of a given skill type over all producers must give total employment of the respective skill group, market clearing for low-skilled workers establishes[17]:

$$L = M \int_{\phi^*}^{\infty} L(\phi) \frac{dG(\phi)}{1 - G(\phi^*)} = zMs \frac{fk(\sigma - 1)}{k - \sigma + 1}, \tag{4.14}$$

whereas for high-skilled workers, I obtain

$$H = M \int_{\phi^*}^{\infty} H(\phi) \frac{dG(\phi)}{1 - G(\phi^*)} + Mf + M_e f_e = M \frac{fk}{k - \sigma + 1} [(1 - z)(\sigma - 1) + 1]. \tag{4.15}$$

Furthermore, there exists a third condition, which I have to consider for characterizing the general equilibrium outcome in the closed economy: I have to make sure that profit-maximizing price-setting is in accordance with firm entry. Following Egger, Egger, and Markusen (2012) I call the respective condition profit maximization condition and combine the solution for the CES price index, $P = M^{1/(1-\sigma)}p(\tilde{\phi})$, with the choice of numéraire, $P = 1$, and the price markup condition in (4.10), applied for the firm with productivity $\tilde{\phi}$. Using (4.13) and the definition of $\tilde{\phi}$, I can solve for

$$M = \left[ \frac{w_l^z w_h^{1-z} \zeta}{\varphi(z)} \right]^{\sigma - 1}, \tag{4.16}$$

[16] As discussed in Melitz (2003), the average productivity $\tilde{\phi}$ equals the weighted harmonic mean of the $\phi$'s of active producers, with relative output levels $x(\phi)/x(\tilde{\phi})$ serving as weights.

[17] In view of constant markup pricing, labor costs are a constant share $(\sigma-1)/\sigma$ of a firm's revenues: $w_l L(\phi) + w_h H(\phi) = r(\phi)(\sigma - 1)/\sigma$. Using $L(\phi) = zl(\phi)$, $H(\phi) = (1-z)h(\phi)$ and accounting for $w_l l(\phi) = w_h h(\phi)$, further implies $L(\phi) = z[(\sigma-1)/\sigma]r(\phi)/w_l$ and $H(\phi) = (1-z)[(\sigma-1)/\sigma]r(\phi)/w_h$, respectively. Finally, combining $w_h = \alpha(z)w_l$ and $M\int_{\phi^*}^{\infty} r(\phi)dG(\phi)/[1-G(\phi^*)] = M\sigma kfw_h/(k-\sigma+1)$ from the appendix and $M_e = M(\phi^*)^k$, allows me to compute (4.14) and (4.15).

where $\zeta \equiv [\sigma/(\sigma-1)]\,[(k-\sigma+1)/k]^{1/(\sigma-1)}\,\{f_e(k-\sigma+1)/[f(\sigma-1)]\}^{1/k}$ is a constant.

Putting together, there are hence four equations, namely (4.7) and (4.14)–(4.16) which jointly determine the four endogenous variables: $z$, $w_l$, $w_h$ and $M$. To determine the equilibrium threshold task, I first combine the two labor market clearing conditions. Dividing (4.14) by (4.15) and solving for the skill premium, I can calculate

$$s = \frac{L}{H}\frac{(1-z)(\sigma-1)+1}{z(\sigma-1)}, \tag{4.17}$$

with $\lim_{z\to 0} s = \infty$, $s = L/[(\sigma-1)H]$ if $z = 1$, and $ds/dz = -(\sigma L)/[(\sigma-1)H(z)^2] < 0$.[18] Noting further that Eq. (4.7) establishes a positive link between $s$ and $z$;[19] $s = \exp[z]$, combining (4.7) and (4.17) therefore gives a unique solution for the skill premium and the threshold task in the closed economy. Thereby the equilibrium solution for $z$ and $s$ depends on a country's endowment with low-skilled and high-skilled workers, respectively. Since firms need high-skilled workers to manage the firm and organize the production process, a country's relative endowment with high-skilled workers must be sufficient large to guarantee that some workers are left for the performance of tasks. To guarantee an interior solution with $z \in (0,1)$, $\exp[1] > L/[(\sigma-1)H]$, and therefore

$$\frac{H}{L} > \frac{1}{(\sigma-1)\exp[1]} \tag{4.18}$$

must hold.[20] This is the parameter domain, I am focusing on in my analysis.

The thus determined equilibrium level of $z$ can be used in (4.15) to compute the equilibrium mass of firms. Thereby, the labor market clearing condition for high-skilled workers determines for a given threshold task the mass of firms that can be active in equilibrium. Finally, accounting for (4.7), I can rewrite (4.16) as follows:

$$M = \left[\frac{w_l\zeta}{\beta(z)}\right]^{\sigma-1}, \tag{4.16$'$}$$

where $\beta(z) = \varphi(z)\alpha(z)^{-(1-z)} = \exp[(1-z)^2/2]$. Eq. (4.16′) determines for a given threshold task and a given mass of producers the low-skilled wage rate $w_l$ and thus the unit cost $w_l/[\phi\varphi(z)]$ that are consistent with the markup pricing condition in (4.10). These insights are summarized in the following Lemma:

**Lemma 1** *Provided that the relative supply of high-skilled workers is sufficiently high, with $H/L > \{(\sigma-1)\exp[1]\}^{-1}$, there exists a unique interior equilibrium, in which firms hire both skill types for the performance of tasks, i.e. $z \in (0,1)$.*

**Proof.** Analysis in the text. ∎

Figure 4.1 provides a graphical illustration on how the four equations (4.7) and (4.14)-(4.16′) interact in determining the general equilibrium variables of interest. Thereby, it is taken into

[18] Intuitively, an increase in $z$ reduces demand for high-skilled relative to low-skilled workers and thus reduces the skill premium.

[19] In the absence of monopsony power of firms, workers are paid their marginal product of labor. With $\alpha_l(i) = 1$ and $\alpha_h(i) = \exp[i]$, the marginal productivity of high-skilled workers is increasing in the threshold task. Thus, if $z$ increases, this implies an increase in the skill premium.

[20] In this case, the skill premium determined by (4.7) is larger than the skill premium determined by (4.17), when the two equations are evaluated at $z = 1$.

account that for a given $w_l$, both (4.15) and (4.16′) establish a positive link between the threshold task $z$ and the mass of producers $M$. Differentiating (4.15), I can compute

$$\left.\frac{dM}{dz}\right|_{Eq.(4.15)} = M\frac{\sigma-1}{(1-z)(\sigma-1)+1} > 0, \qquad \left.\frac{d^2M}{dz^2}\right|_{Eq.(4.15)} = 2M\frac{(\sigma-1)^2}{[(1-z)(\sigma-1)+1]^2} > 0, \tag{4.19}$$

which implies that locus (4.15) establishes a positive and convex relationship between $M$ and $z$, as depicted in the upper panel of Figure 4.1. Furthermore, differentiating (4.16′) gives

$$\left.\frac{dM}{dz}\right|_{Eq.(4.16')} = M(\sigma-1)(1-z) > 0, \qquad \left.\frac{d^2M}{dz^2}\right|_{Eq.(4.16')} = M(\sigma-1)\left[(\sigma-1)(1-z)^2-1\right], \tag{4.20}$$

with $d^2M/dz^2|_{Eq.(4.16')}$ being positive for small levels of $z$ if $\sigma > 2$ and negative for high ones. This establishes the S-shape of locus (4.16′) in the upper panel of Figure 4.1, while the relationship is concave for $\sigma < 2$.[21] The lower panel of Figure 4.1 captures (4.7) and (4.17) in the $(s, z)$-space. To see how the equilibrium outcome is determined one has to start in the lower panel, where equilibrium values of $z$ and $s$ are represented by the intersection point of (4.7) and (4.17). I use index $c$ to refer to an equilibrium with competitive labor markets. Combining the equilibrium threshold level $z^c$ with (4.15) in the upper panel, then determines the equilibrium mass of firms $M^c$. Finally, given $z^c$ and $M^c$, the position of locus (4.16′) has to be adjusted in order to bring the low-skilled wage in accordance with constant markup-pricing and the price index corresponding to Eq. (4.1). Hereby, it is notable that an leftward shift of (4.16′) refers to an increase in $w_l$.

In Figure 4.1, (4.16′) is plotted such that it intersects (4.15) at $(M^c, z^c)$ from below. As outlined in the next subchapter, this is a prerequisite for a stable equilibrium in a minimum wage economy, which is analyzed below. To shed further light on this issue, it is notable that

$$\left.\frac{dM}{dz}\right|_{Eq.(4.16')}^{z=z^c, w_l=w_l^c} \gtreqless \left.\frac{dM}{dz}\right|_{Eq.(4.15)}^{z=z^c} \tag{4.21}$$

is equivalent to $\hat{z} \gtreqless z^c$, with

$$\hat{z} \equiv \frac{2\sigma-1-\sqrt{4\sigma-3}}{2(\sigma-1)} \tag{4.22}$$

and $\hat{z} \in (0,1)\ \forall\ \sigma > 1$. It therefore follows that in the competitive equilibrium locus (4.16′) intersects locus (4.15) from below if $z^c < \hat{z}$, requiring that

$$\frac{H}{L} > \frac{(1-\hat{z})(\sigma-1)+1}{\hat{z}(\sigma-1)\exp[\hat{z}]} \equiv \hat{h}, \tag{4.23}$$

which provides a more restrictive parameter constraint than (4.18). This is illustrated in Figure 4.1 where the dashed curve in the upper panel indicates a scenario with $H/L = \hat{h}$ and $z = \hat{z}$. Starting from such an outcome, an increase in $H/L$ – due to a decline in $L$ for a given $H$ – shifts locus (4.17) inwards and locus (4.16′) to the left in Figure 4.1, thereby establishing an equilibrium in which (4.16′) intersects (4.15) from below.[22]

[21] Throughout the chapter, $\sigma > 2$ is assumed for illustrative reasons, while in principle, $\sigma > 1$ is sufficient for establishing the results.

[22] Of course, the analysis above does not ensure that (4.15) and (4.16′) have a unique intersection point. Looking

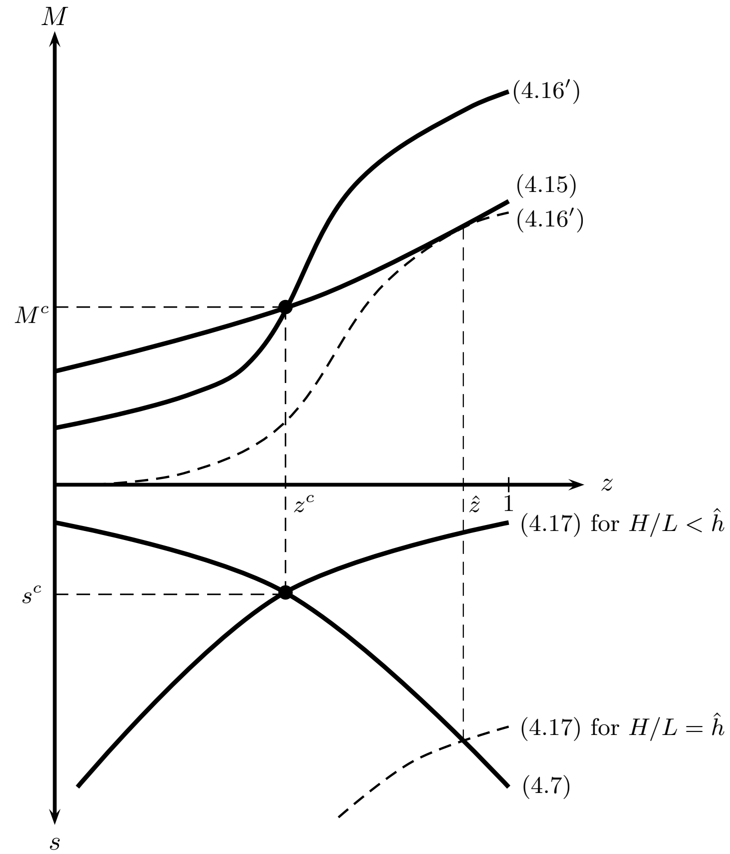


Figure 4.1: Equilibrium with fully flexible wages in the closed economy

### 4.2.3 Equilibrium with a minimum wage for low-skilled workers

It is an empirically well documented fact for industrialized economies, that involuntary unemployment is especially persistent among low-skilled workers. Therefore, I introduce a (real) binding minimum wage $w$, that is set by the government for this skill type. This implies that the labor market clearing condition for low-skilled workers no longer holds, and the adding-up condition for low-skilled workers now determines unemployment. To be more specific, (4.14) is replaced by

$$(1-u)L = zMs\frac{fk(\sigma-1)}{k-\sigma+1} \tag{4.24}$$

with $u$ denoting the unemployment rate, which is positive if the minimum wage is binding. While (4.7), (4.15) and (4.16′) remain unaffected by this modification (except for $w_l$ being now determined exogenously by minimum wage $w$), the determination of the equilibrium values for $z$

at the shapes of the two loci (4.15) and (4.16′), I cannot rule out that there exists a second intersection point to the right of $(z^c, M^c)$. However, in such an intersection point $z > z^c$ and $M > M^c$ must hold, and this is inconsistent with an equilibrium, as can be seen when substituting (4.7) into (4.14) to obtain $L = ze^zMfk(\sigma-1)/(k-\sigma+1)$. Since the latter holds if $z = z^c$ and $M = M^c$, it must be violated if $z > z^c$ and $M > M^c$, rendering an intersection point to the right of $(z^c, M^c)$ inconsistent with market clearing for low-skilled workers.

and $M$ changes. In contrast to the previous chapter with fully flexible wages, (4.15) and (4.16′) now jointly determine the threshold task and the prevailing number of firms in the economy. Given $z$, (4.7) then determines the skill premium. Finally, substitution of (4.7) and (4.15) into (4.24), allows me to relate the unemployment rate to the computed skill premium:

$$u = 1 - \ln[s]s\frac{H(\sigma-1)}{L[(1-\ln[s])(\sigma-1)+1]}, \tag{4.25}$$

with $du/ds < 0$. To see how the general equilibrium variables are linked in the minimum wage economy, I can build on insights from Figure 4.1. Noting that the minimum wage is binding if and only if $w > w_l^c \equiv \underline{w}$, because otherwise firms would simply pay the competitive wage and unemployment would fall to zero, it is immediate that in the minimum wage economy locus (4.16′) is shifted leftwards relative to the benchmark scenario with competitive wages. Moreover, provided that the relative supply of high-skilled workers is sufficiently large, i.e. $H/L > \hat{h}$ as discussed in the previous chapter, locus (4.16′) intersects (4.15) from below, implying that an leftward shift of locus (4.16′) gives $z < z^c$ and $M < M^c$.[23] Since low-skilled workers are more expensive in the minimum wage economy, firms assign them to a lower range of tasks. This implies that more high-skilled labor is used as a variable input, leaving less resources for entering the lottery and to manage the firm and organize the production process and thereby lowering the mass of competitors.

Now it could be possible that the minimum wage is so high that employment of low-skilled workers becomes eventually unattractive even for the least complex task, resulting in $z = 0$. To rule out such a corner solution, I focus on a parameter domain for which (4.15) and (4.16′) intersect at some $z \in (0,1)$. This is the case if $w < \overline{w} \equiv \exp[1/2]\zeta^{-1}[H(k-\sigma+1)/(fk\sigma)]^{1/(\sigma-1)}$. If an interior equilibrium with $z \in (0,1)$ exists in the minimum wage economy, it follows from the properties of (4.15) and (4.16′) that the equilibrium is unique. Furthermore, the equilibrium is stable, as can be inferred from considering a point like A in the upper right panel of Figure 4.2. In point A the mass of firms is too low for a given $z$, and $M$ will increase until it is consistent with the labor market clearing condition for high-skilled workers. However, in view of (4.16′), the prevailing $z$ is now too small for a given $M$. Hence, with constant markup pricing $z$ must increase in order to restore $P = 1$. This mechanism continues until the intersection point of (4.15) and (4.16′) is reached.

With the solution for $z$ and $M$ at hand, skill premium $s$ in the minimum wage economy is determined in the lower right panel of Figure 4.2. Locus (4.25) in the lower left panel of Figure 4.2 finally determines unemployment rate $u$ in the minimum wage economy. Thereby, locus (4.17) is used to construct the intercept of locus (4.25) with the vertical axis at the skill premium $s = s^c$, which leads to $u = 0$. With these insights, I am now equipped to discuss the group-specific effects of a binding minimum wage. Looking at the group of high-skilled workers, there are two counteracting effects on their income triggered by an increase in $w_l$. On the one hand, a higher wage for low-skilled workers, implies that high-skilled workers are employed for a larger range of tasks in all active firms. This labor demand stimulus is counteracted by a decline in the mass of firms entering the market, which lowers demand for both skill types ceteris paribus. To see which of the two effects dominates I can substitute $w_h = \alpha(z)w$ in (4.15) and (4.16′) to compute

$$w_h = \left[\frac{H(k-\sigma+1)}{fk}\right]^{\frac{1}{\sigma-1}} \zeta^{-1} \exp\left[\frac{1+z^2}{2}\right] \left[\frac{1}{(1-z)(\sigma-1)+1}\right]^{\frac{1}{\sigma-1}}. \tag{4.26}$$

[23]From the analysis in the previous chapter I know that an outcome with $z > z^c$ and $M > M^c$ is inconsistent with an equilibrium.

Noting from above that introduction of a binding minimum wage lowers threshold task $z$, it follows from (4.26) that $dw_h/dw_l < 0$. Accordingly, high-skilled workers are worse-off in the minimum wage economy than in the benchmark model with competitive labor markets.

Regarding the group of low-skilled workers, there are winners and losers. Those, who keep their job in a minimum wage economy, see their income rising, whereas those who lose their job are worse off than in the competitive labor market scenario. To obtain a compulsory measure for the group-specific welfare of low-skilled workers, I can look at $(1-u)w$. Substituting $s = w_h/w$ into (4.24), it is immediate that introduction of the minimum wage, by lowering $M$, $z$ and $w_h$, unambiguously lowers per-capita income (and thus welfare) of low-skilled workers.

While the skill premium $s = \alpha(z)$ is lower in the minimum wage economy than in the benchmark model with competitive labor markets, setting $w > w_l^c$ increases the return to high-skilled workers relative to the expected income of low-skilled workers. This can be seen from rewriting Eq. (4.24) as follows

$$\frac{w_h}{(1-u)w} = \frac{L}{zM}\frac{k-\sigma+1}{fk(\sigma-1)} \tag{4.27}$$

and noting from the discussion above that the introduction of a binding real minimum wage lowers both $z$ and $M$. Finally, since both skill types end up with a lower per-capita income in a minimum wage economy, compared to a situation with fully flexible wages, it immediately follows that welfare, measured by per-capita income $W \equiv I/(H+L)$, where $I = (1-u)Lw + Hw_h$ denotes aggregate labor income, is reduced. Proposition 8 summarizes the insights of introducing a binding real minimum wage for low-skilled workers.

**Proposition 8** *For a binding minimum wage $w \in (\underline{w}, \overline{w})$, there exists a unique and stable interior equilibrium with $z < z^c$ and $M < M^c$ if $H/L > \hat{h}$. Introduction of the minimum wage lowers welfare relative to the benchmark of an economy with a competitive labor market and it generates involuntary unemployment of low-skilled workers. Looking at the group-specific effects, the introduction of a binding minimum wage $w \in (\underline{w}, \overline{w})$ lowers welfare of high-skilled and low-skilled workers and – although lowering the skill premium – increases the relative income of high-skilled workers.*

**Proof.** Analysis in the text. ■

### 4.2.4 Comparative-static analysis

I complete the discussion of the closed economy, by shedding light on how changes in key model parameters affect the general equilibrium variables of interest. An obvious candidate for this comparative static exercise is a variation in the minimum wage. However since the effects of changes in $w$ on the variables of interest are monotonic, the respective insights for this comparative static exercise can be directly inferred from Proposition 8 and do not require further discussion. In the subsequent analysis, I therefore focus on changes in factor endowments and the differential effects these changes have under the two labor market regimes studied in Subsection 4.2.2 and 4.2.3. Thereby, I restrict attention to parameter constellations with $H/L > \hat{h}$. Starting with the benchmark situation where both wages are determined in competitive labor markets, an increase in $L$ shifts locus (4.17) outwards, as indicated by the dotted line in Figure 4.3. The additional supply of low-skilled workers is absorbed by firms in assigning this skill type to a broader range of tasks, which causes an increase in the threshold task $z^c$ and makes all active firms less productive. Using less high-skilled workers in the production process implies that more firms can enter the market, and thus $M^c$ goes up. To discuss the impact on factor returns,

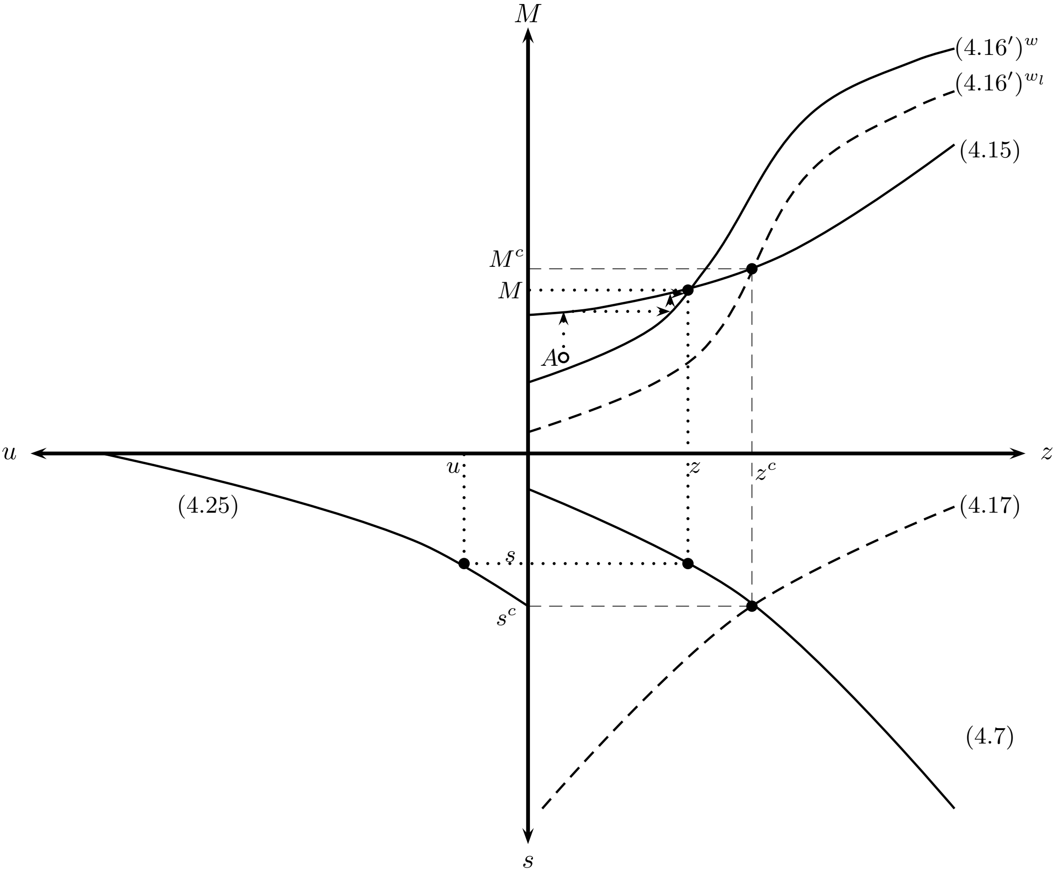


Figure 4.2: Equilibrium with a minimum wage for low-skilled workers in the closed economy

note first that the labor market clearing condition for high-skilled workers remains unaffected by a change in $L$. Hence, locus (4.16′) has to shift rightwards, to intersect locus (4.15) at the new values for $z^c$ and $M^c$, implying that the wage rate for low-skilled workers falls in response to an increase in $L$. Things are different for high-skilled workers. Since this skill type becomes relatively scare, the skill premium increases in a scenario with competitive labor markets. But do high-skilled workers also gain in absolute terms, i.e. do they experience an increase in their real wage? Clearly, there are two counteracting effects on the labor demand for this skill type. On the one hand, the increase in $z$ reduces labor demand for high-skilled workers, while, on the other hand, additional firm entry stimulates demand for high-skilled workers. Since $dw_h/dz > 0$ according to (4.26), it is the latter effect that dominates, and I can thus safely conclude that an increase in the supply of low-skilled workers raises $w_h$. Finally, to detect the implications of an increase in the supply of low-skilled workers for aggregate labor income $I = Lw_l + Hw_h = Mr(\tilde{\phi})$, I make use of $r(\tilde{\phi}) = \sigma k f w_h/(k - \sigma + 1)$ from the appendix and note from above that a larger supply of low-skilled workers raises both $w_h$ and $M$. This implies that aggregate labor income goes up. However, this does not mean that per-capita income and thus welfare increases as well, because the higher labor income is now distributed over a larger population. To shed light on this issue, I can substitute $r(\tilde{\phi}) = \sigma k f w_h/(k-\sigma+1)$ together with (4.7) and the two labor market clearing conditions (4.14) and (4.15) into $W = (Lw_l + Hw_h)/(L+H) = Mr(\tilde{\phi})/(L+H)$ to calculate

$$W = \frac{\sigma w_h}{z(\sigma-1)(\exp[z]-1)+\sigma}. \tag{4.28}$$

From inspection of (4.28), the increase in $w_h$ triggered by the higher supply of low-skilled workers stimulates per-capita income, while the implied increase in $z$ reduces welfare due to the negative productivity effect, as all producers perform less tasks with high-skilled workers. Accounting for (4.26) I can furthermore calculate

$$W = \exp\left[\frac{1}{2}(1+z^2)\right] \frac{[(1-z)(\sigma-1)+1]^{-\frac{1}{\sigma-1}}}{z\exp[z](\sigma-1)+(1-z)(\sigma-1)+1}\hat{\zeta}, \tag{4.29}$$

where $\hat{\zeta} \equiv [H(k-\sigma+1)/fk]^{1/(\sigma-1)}\sigma\zeta^{-1}$ and

$$\frac{dW}{dz} = W\left[\frac{(\exp[z]-1)(z^2-z-1)(\sigma-1)+z}{z(\sigma-1)(\exp[z]-1)+\sigma} + \frac{1}{(1-z)(\sigma-1)+1}\right]. \tag{4.30}$$

Eq. (4.29) establishes a non-trivial relationship between $z$ and $W$, with the sign of (4.30) depending on $\sigma$ and the initial value of $z$. Clearly, if $z$ is close to zero, $dW/dz > 0$ holds for all $\sigma$, while things are different for $z > 0$. In particular for large $\sigma$-values it cannot be ruled out that $dW/dz < 0$ for sufficient large $z$. To see this, one can evaluate (4.30) for instance at $\sigma = 2$ and $\sigma = 8$, with corresponding $\hat{z}$-values of $\hat{z}|_{\sigma=2} = 0.382$ and $\hat{z}|_{\sigma=8} = 0.69$, respectively. This gives $dW/dz|^{\sigma=2}_{z=0} = 0.5$, $dW/dz|^{\sigma=2}_{z=0.3} = 0.53$, $dW/dz|^{\sigma=2}_{z=\hat{z}} = 0.53$ and $dW/dz|^{\sigma=8}_{z=0} = 0.125$, $dW/dz|^{\sigma=8}_{z=0.3} = -0.14$ and $dW/dz|^{\sigma=8}_{z=\hat{z}} = -0.29$.

Let us now turn to the minimum wage economy, for which the effect of changes in $L$ are depicted by Figure 4.4. Since in this case a higher $L$ does neither affect the position of locus (4.15) nor the position of locus (4.16′), it leaves the mass of producers $M$ as well as the threshold task $z$ unaffected. Furthermore, since a change in $L$ does not affect the position of locus (4.7) in the lower right panel of Figure 4.4 either, the skill premium also remains unaffected by an expansion of low-skilled labor supply. Of course, an increase in $L$ shifts locus (4.17) outwards in the lower right panel of Figure 4.4 and thus triggers a clockwise rotation of locus (4.25) in the lower left panel of the figure. This implies an increase in unemployment rate $u$. Similar to Brecher (1974), labor supply of unskilled workers in the minimum wage economy is not a binding constraint, and hence an increase in the respective supply is fully absorbed by a pari passu increase in unemployment. As a consequence, an increase in labor supply $L$ leaves high-skilled workers unaffected and lowers per-capita income of low-skilled workers, which is instrumental for a decline in welfare.

**Proposition 9** *With competitive labor markets, an increase in L raises the range of tasks performed by low-skilled workers. This triggers a decline in the productivity of intermediate goods producers and leads to additional firm entry. The higher supply of L reduces per-capita income of low-skilled workers and increases welfare of high-skilled workers while overall welfare effects are ambiguous. With a binding minimum wage, an increase in the supply of low-skilled workers is fully absorbed by a pari passu increase in unemployment. This lowers welfare and leaves all other variables unaffected.*

**Proof.** Analysis in the text ■

The implications of an increase in the supply of high-skilled workers when wages are fully flexible

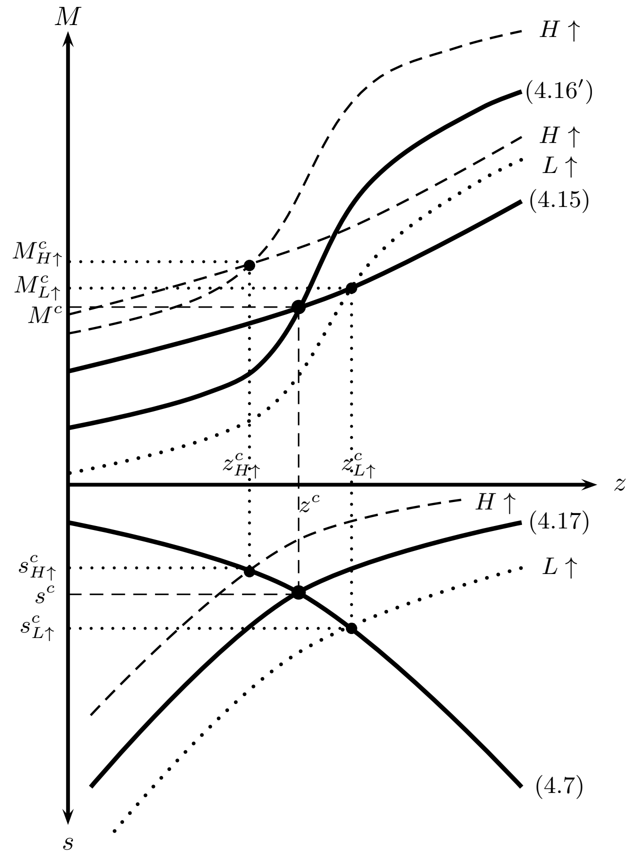


Figure 4.3: Equilibrium with fully flexible wages in the closed economy

are indicated by the dashed lines in Figure 4.3. A higher $H$ shifts locus (4.17) inwards and therefore lowers the threshold task (and the skill premium). As a consequence, firms become more productive, because high-skilled workers are now used for a broader range of tasks. However, in an economy with competitive labor markets the additional supply of high-skilled workers is only partly absorbed by this firm-internal adjustment. Since low-skilled workers are replaced by high-skilled ones, additional firms must enter to restore market clearing for low-skilled workers, according to (4.14). This is captured by an upward shift of locus (4.15) in the upper panel of Figure 4.3. And the upward shift of (4.15) paired with the decline in $z^c$ implies that (4.16′) must shift leftwards, which requires an increase in the low-skilled wage $w_l^c$. In contrast, the impact of an increase in $H$ on the real wage of high-skilled workers is less clearcut. On the one hand, an increase in the supply of a skill type renders this factor less scare and thus lowers its return ceteris paribus. On the other hand, the increase in the skilled labor supply leads to additional firm entry and thus stimulates demand for high-skilled workers as variable production input as well as demand for high-skilled workers as a fixed input to manage the firm and organize the production process. To shed further light on this issue, I can combine (4.14) and (4.16′) and account for $w_h = w_l \alpha(z)$ from (4.7) to compute

$$w_h = \left[\frac{L(k-\sigma+1)}{fk(\sigma-1)}\right]^{\frac{1}{\sigma-1}} \zeta^{-1} \exp\left[\frac{1+z^2}{2}\right]\left[\frac{1}{z\exp[z]}\right]^{\frac{1}{\sigma-1}}. \tag{4.31}$$

Differentiating (4.31) with respect to $z$ gives

$$\frac{dw_h}{dz} = w_h\left[z - \frac{1+z}{z}\frac{1}{\sigma-1}\right] \tag{4.32}$$

which is negative as long as $z < (1+\sqrt{4\sigma-3})/2(\sigma-1) \equiv \tilde{z}$. Noting from the definition of $\hat{z}$ in (4.22), that $\tilde{z} > \hat{z}$ as long as $\sigma \leq 3+\sqrt{5}$, I can furthermore conclude that $dw_h/dz < 0$ and thus $dw_h/dH > 0$ holds in the relevant parameter domain if the elasticity of substitution is low. However, if $\sigma > 3+\sqrt{5}$, I cannot rule out that $dw_h/dH < 0$ for large initial values for $z$. Finally, as a larger supply of high-skilled workers raises the mass of active firms, total labor income increases. To discuss the impact on a country's welfare level, I can infer from (4.28), that given the increase in $w_h$ and the reduction in $z$, which leads to a positive productivity effect, a country's per-capita income is increasing in its endowment with high-skilled workers.[24]

Again, an increase in the supply of high-skilled workers exerts a different impact on the general equilibrium variables of interest, when the wage rate for low-skilled workers is fixed by a binding minimum wage. In a minimum wage economy, an increase in $H$ shifts locus (4.15) upwards, as indicated by the dotted curve in Figure 4.4. Hence, similar to the benchmark scenario with competitive labor markets, the additional supply of high-skilled workers allows for additional firm entry, so that $M$ increases. However, with low-skilled labor supply being not a binding constraint in the minimum wage economy, the additional demand for low-skilled labor at the extensive margin – triggered by the additional firm entry – does not increase the factor return of low-skilled workers implying that intermediate goods producers have no incentive to reduce the range of tasks performed by low-skilled workers. Moreover, since the new intersection point between locus (4.15) and locus (4.16′) moves north-east in Figure 4.4, there is a magnification effect in the sense of $dM/dH > 0$, so that the range of tasks performed by low-skilled workers increases. Hence, with a binding real minimum wage an increase in $H$ reduces the range of tasks performed by high-skilled workers and, as can be seen in the lower right panel of Figure 4.4, it raises the skill premium. Moreover, the increase in $z$ implies a fall in productivity for intermediate goods producers. The implications for the wage rate of high-skilled workers can be seen when rewriting Eq. (4.7) as $w_h = w\exp[z]$. Since $z$ rises in $H$, a higher supply of high-skilled workers increases $w_h$. Hence, high-skilled workers gain in relative[25] and absolute terms, which is in contrast to the benchmark situation with competitive wages. However, also low-skilled workers gain from the additional supply of $H$, due to additional employment of this skill type. This can be seen from Figure 4.4, when noting that a higher supply of high-skilled workers shifts locus (4.17) inwards, and therefore rotates locus (4.25) counter-clockwise in the lower left panel of that figure. As a consequence, a higher skill premium must therefore be associated with lower unemployment of low-skilled workers, implying a higher per-capita income $(1-u)w$ of this skill group. This is intuitive as the demand for low-skilled workers is stimulated by a increase in $z$ and $M$. Finally, the increase in the mass of intermediate producers also leads to higher total labor income and, since both skill groups benefit, to higher per-capita income and thus welfare.

[24] As shown in the appendix, the positive impact is also present if $\sigma$ is large and $dw_h/dH < 0$ materializes.

[25] This can bee seen from (4.27). Accounting for $dz/dH > 0$ and $dM/dH > 0$, the relative per-capita income of high-skilled workers $w_h/[(1-u)w]$ clearly increases.

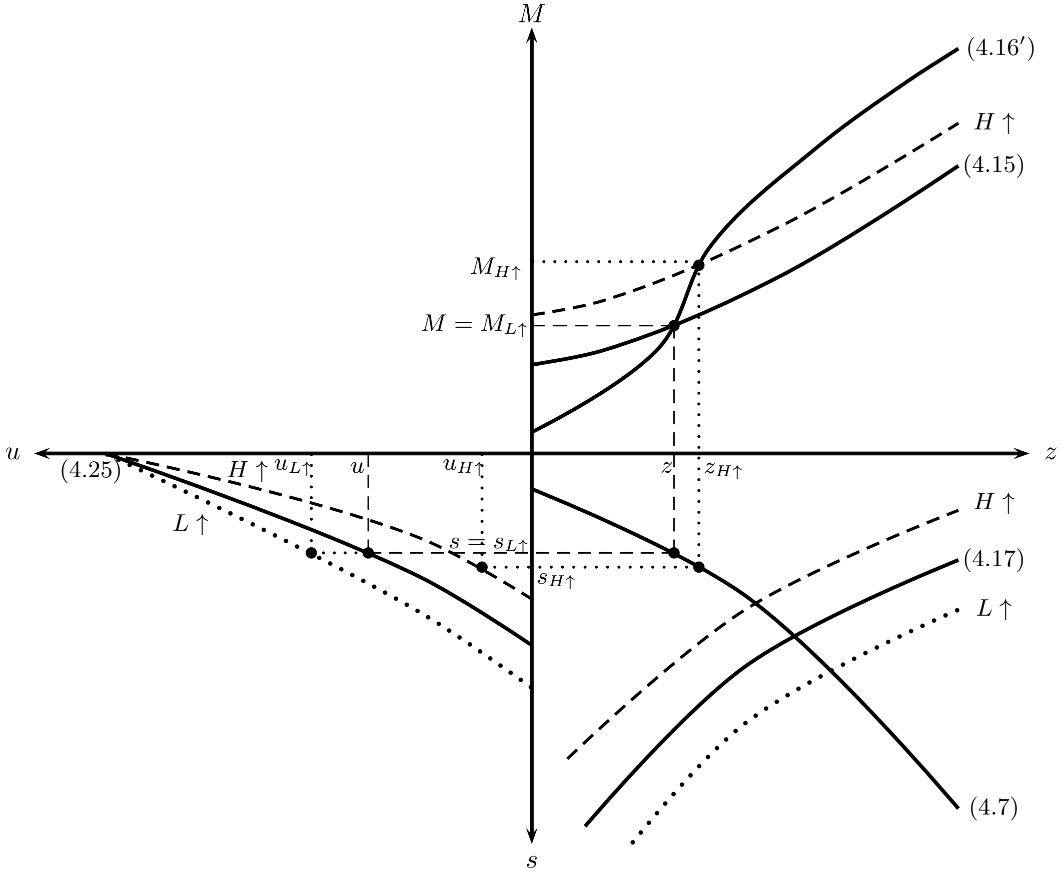


Figure 4.4: Endowment changes with a binding minimum wage

**Proposition 10** *With fully flexible wages, an increase in the supply of high-skilled workers reduces the range tasks performed by low-skilled workers, thereby increasing the productivity of active producers and the mass of active firms. Low-skilled workers receive a higher income and the skill premium for high-skilled workers is reduced. The impact on high-skilled wages are ambiguous and depend on the elasticity of substitution between variants of the intermediate. Only if $\sigma \leq 3 + \sqrt{5}$ wages will increase, while for $\sigma > 3 + \sqrt{5}$ the impact on wages is ambiguous. Irrespective of the change in $w_h$, welfare is positively affected by the expansion of $H$. With a binding minimum wage, an increase in $H$ raises the mass of firms and the threshold task, thereby reducing the productivity of active producers. High-skilled workers gain in absolute and relative terms, and the unemployment rate for low-skilled workers goes down, implying that welfare must increase.*

**Proof.** Analysis in the text. ■

This completes the discussion of the closed economy.

# 4.3 The open economy

## 4.3.1 Basic structure

It is the purpose of this chapter to shed light on the assignment of skills to tasks and a firm's production process if the country under consideration opens up to trade. I thereby discuss the differential consequences of trade between two countries indexed by $j = 1, 2$, whose economies are characterized as in the previous chapter, when labor markets are perfectly competitive or when there is a binding minimum wage for low-skilled workers. To keep the analysis tractable, I thereby abstract from any trade impediments and assume that all firms export. This simplification seems to be justified, because in my model the revenue ratio of any two firms and thus the export decision is fully characterized by baseline productivity levels, and hence my model is not equipped to shed new light on the exporting decision of firms (see, for instance, Melitz, 2003; Bernard, Redding, and Schott, 2007; Melitz and Ottaviano, 2008). Therefore, I prefer the more parsimonious structure without self-selection of firms into exporting in order to focus on those aspects of the model that are new in the literature.

When the country opens up for trade, intermediate goods producers can raise their profits by selling their variety to the foreign market. Abstracting from any trade impediments, $Y$ and $P$ are identical to all firms irrespective of their home country. Furthermore, without selection into exporting, trade does not alter the firm entry mechanism, so that (4.11)-(4.13) still hold after a country's movement from autarky to trade. As discussed in the previous chapter, the cutoff productivity is independent of the labor market regime, hence $\phi_1^* = \phi_2^* \equiv \phi^*$ and $\tilde{\phi}_1 = \tilde{\phi}_2 \equiv \tilde{\phi}^*$ hold in the benchmark scenario of competitive labor markets as well as the minimum wage economy. Constant markup pricing in both economies implies $\pi_j(\phi^*) = r_j(\phi^*)/\sigma - f w_{hj} = 0$, and therefore $r_1(\phi^*)/\sigma = f w_{h1}$ and $r_2(\phi^*)/\sigma = f w_{h2}$. Accounting for (4.2), (4.7) which is the same as in the closed economy, (4.10) and the definition of $\beta(z)$ I can compute

$$\frac{w_{l1}}{w_{l2}} = \left[\frac{\alpha(z_2)}{\alpha(z_1)}\right]^{\frac{1}{\sigma}} \left[\frac{\beta(z_1)}{\beta(z_2)}\right]^{\frac{\sigma-1}{\sigma}} = \exp\left\{\frac{z_2 - z_1}{2}\left[2 - \frac{\sigma-1}{\sigma}(z_1 + z_2)\right]\right\}, \tag{4.33}$$

which determines $z_1$ relative to $z_2$ in the open economy and implies $z_1 < z_2$ if $w_{l1} > w_{l2}$. To compare prices of the marginal firms in the two countries, first substitute (4.7) into (4.10), which entails $p_j(\phi^*) = \sigma w_{lj}/[(\sigma-1)\phi^*\beta(z_j)]$. As the cutoff productivity is the same in both economies, I get $p_1(\phi^*)/p_2(\phi^*) = w_{l1}\beta(z_2)/[w_{l2}\beta(z_1)]$. Accounting for (4.33) and the definition of $\beta(z)$ then gives

$$\frac{p_1(\phi^*)}{p_2(\phi^*)} = \left[\frac{\alpha(z_2)\beta(z_2)}{\alpha(z_1)\beta(z_1)}\right]^{\frac{1}{\sigma}} = \exp\left[\frac{z_2^2 - z_1^2}{2\sigma}\right]. \tag{4.34}$$

To analyze the impact of intermediates trade on the general equilibrium variables of interest, note first that both adding up conditions for low-skilled and high-skilled workers are the same as in the closed economy. However, as the final good is now assembled with intermediate varieties from both countries, the corresponding price index and therefore (4.16′) need to be adjusted. In the open economy the mass of available intermediate varieties has changed to $M_t = M_1 + M_2$, implying that the price index in the open economy is given by $P = [M_1 p_1(\tilde{\phi})^{1-\sigma} + M_2 p_2(\tilde{\phi})^{1-\sigma}]^{1/(1-\sigma)}$. Accounting for (4.7) and (4.10) together with $P = 1$ this can be written as (see the appendix)

$$M_j = \left[\frac{w_{lj}\zeta}{\beta(z_j)}\right]^{\sigma-1}\left[1 + \frac{M_{-j}}{M_j}\left(\frac{p_j(\phi^*)}{p_{-j}(\phi^*)}\right)^{\sigma-1}\right]^{-1}. \tag{4.35}$$

This equation still establishes a positive relationship between the mass of producers and the threshold task in the home country $j$, for given values of $z$ and $M$ in the foreign country $-j$. With these insights, I am now equipped to study the impact of trade on the variables of interest. I thereby start with a situation, in which both countries are fully symmetric and postpone a discussion of country asymmetries to the extensions in Chapter 4.4. In Chapter 4.3.2, I thereby analyze the implications of trade when labor markets are perfectly competitive, whereas in Chapter 4.3.3, I shed light on the consequences of trade in a minimum wage economy.

### 4.3.2 Trade with perfect labor markets

With fully flexible wages, the eight endogenous variables in the open economy, $w_{lj}$, $w_{hj}$, $z_j$ and $M_j$, for $j = 1, 2$ are determined by condition (4.7) and the labor market clearing conditions (4.14) and (4.15) – applied to the two economies – Eq. (4.33) and finally the profit maximization condition in the open economy, Eq. (4.35), applied for country $j$.[26] To illustrate the equilibrium in the open economy, I can use the same graphical tool, as in the previous chapter. If wages are set in perfectly competitive markets, the equilibrium threshold task and the skill premium are jointly determined by (4.7) and (4.17), which are plotted in the lower panel in Figure 4.5. As both loci remain unaffected by an opening up to trade, the skill premium and the threshold task are the same as in the closed economy, i.e. $s_a^c = s_j^c$ and $z_a^c = z_j^c$, where index $a$ refers to autarky variables. Moreover, since the labor market clearing condition for high-skilled workers and thus locus (4.15) remains unaffected as well, also the mass of firms in country $j$ stays constant, i.e. $M_a^c = M_j^c$. These findings indicate, that the intersection point between loci (4.15) and (4.35) in the upper panel of Figure 4.5 is the same as in the closed economy equilibrium. According to (4.33) and (4.34), prices for the cutoff firm in each market are identical when both countries are fully symmetric, implying that (4.35) reads $M_j = [w_{lj}\zeta/\beta(z_j)]^{\sigma-1}(1/2)$. Hence, compared to its closed economy counterpart in (4.16′), the profit maximization condition (4.35) is shifted rightwards for any given wage rate for low-skilled workers $w_{lj}^a$. Opening up to trade raises the mass of available intermediate varieties to $M_t = M_1 + M_2$. This increases country-specific output $Y$ and stimulates demand for each firm, according to (4.2). Therefore, aggregate labor demand for each skill type is stimulated. With fully flexible wages, $w_l$ must increase, to bring the economy back to $z_j^c = z_a^c$ and $M_j^c = M_a^c$. According to $w_h = w_l\alpha(z)$ the wage rate for high-skilled workers increases by the same extend, so that the skill premium remains at the autarky level. Similar to Krugman (1979), trade between two fully symmetric countries therefore leads to a positive income and thus welfare effect, while leaving all other variables of interest unaffected. These findings are summarized in the following proposition.

**Proposition 11** *If wages are fully flexible, a country's opening up to trade with a symmetric partner country has no impact on the skill premium, the firm internal assignment of skills to tasks and the mass of active firms. However, trade increases the real wage for both skill types and thus welfare.*

**Proof.** Analysis in the text. ■

The findings from Proposition 11 do not hinge on the assumption that both countries are symmetric in their relative endowments with high-skilled and low-skilled workers. This can be easily inferred from the discussion above. As any change in the supply of $L$ or $H$ in Foreign, leaves the position of loci (4.7), (4.15) and (4.17) in Home unaffected, it does not affect $z_j$, $s_j$ and $M_j$. Thus, when wages are fully flexible, trade between two countries that differ in their

[26] Note that (4.35) can only be applied for one country. Applying it for the other country simply confirms that $P_1 = P_2 = 1$.

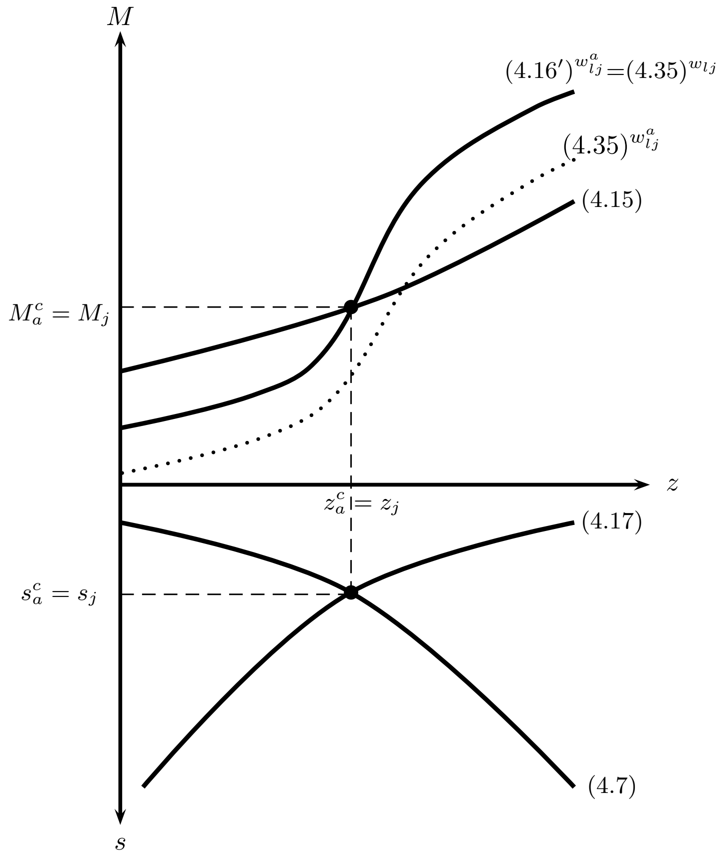


Figure 4.5: Trade with fully flexible wages

relative endowments still exerts only a positive income and welfare effect, but does not change the other variables of interest. Moreover, the strength of these effects depends on the stimulus in labor demand for the two skill types. The higher the mass of intermediate producers in the foreign country, the larger is the positive demand shock by opening up for trade from a domestic country's perspective. As $M_{-j}$ is increasing in $L_{-j}$ and $H_{-j}$, welfare effects at Home are therefore increasing in the size of the foreign factor markets.

### 4.3.3 Trade with a minimum wage for low-skilled workers

In this chapter, I again study trade between two fully symmetric countries, with the mere difference, that governments in each country now set a binding minimum wage, $w_1 = w_2$. To determine the eight endogenous variables $s_j$, $z_j$, $M_j$ and $u_j$, for $j = 1, 2$ I can make use of (4.7), (4.15) and (4.24) – applied to both economies – (4.33) and (4.35). As discussed in the closed economy, the labor market clearing condition for high-skilled workers and the profit maximization condition now jointly determine the mass of firms and the threshold task. With perfect symmetry between the two economies, (4.35) reads $M_j = [w_j\zeta/\beta(z_j)]^{\sigma-1}(1/2)$ and is shifted rightwards relative to its closed economy counterpart in Figure 4.6, implying that $M$ and $z$ are increased compared to the autarky scenario. Since all other things equal, final goods producers have access to more differentiated intermediate goods, final output increases due to a standard division of labor effect. This stimulates demand for intermediate goods, according to (4.2), and therefore aggregate labor demand for each skill type. While the factor price for low-skilled workers is fixed and remains unaffected, the wage rate for high-skilled workers will increase.[27] Thus, the relative factor costs have changed in favor of low-skilled workers and firms respond to the cost increase by raising the threshold task to $z > z^a$. A lower skill intensity implies that more high-skilled workers are left to entering the lottery and to manage the firm and organize the production process, so that the mass of local intermediate goods producers increases in both countries relative to the closed economy. The higher $z$ furthermore implies an increase in the skill premium, as can be seen in the lower right panel of Figure 4.6. Finally, the adjustment in $z$ and $M$ contribute to an increase in low-skilled labor employment and a decline in unemployment rate $u$ as depicted in the lower left panel of Figure 4.6.[28] From inspection of Eq. (4.27) there are counteracting effects on the relative per-capita income of high-skilled workers. However, solving (4.15) for $M$ and substituting the respective expression into (4.27), I can compute

$$\frac{w_h}{(1-u)w} = \frac{Lfk[(1-z)(\sigma-1)+1]}{Hz(k-\sigma+1)} \tag{4.36}$$

which, according to $z < z^a$, implies that trade unambiguously increases the relative per-capita income of high-skilled workers. Finally, the increase in the wage rate for high-skilled workers and the reduction in the unemployment rate triggers an increase in welfare. These findings are summarized in the following proposition:

**Proposition 12** *With a binding minimum wage for low-skilled workers, a country's opening up to trade with a symmetric partner country reduces the unemployment rate for low-skilled workers and increases the real wage, the skill premium and the relative per-capita income of high-skilled workers. Welfare is unambiguously higher in the open economy than in the closed economy and all active firms produce a broader range of tasks with low-skilled workers, which reduces observed labor productivity.*

**Proof.** Analysis in the text. ■

The results in Proposition 12 demand further discussion. First, there is a crucial difference to the findings in the literature on heterogeneous firms. Usually, the claim in the literature is that trade liberalization has a positive impact on economy-wide labor productivity by relocating productive factors towards high-productive firms, which have excess to export markets and thus benefit disproportionately from trade liberalization (see Melitz, 2003). Thereby, the firm-level productivity stays constant, but selection to more productive firms increases the economy-wide productivity. In my model, this channel is closed, as trade is costless and all firms participate in exporting. This leaves the relative performance of any two firms unaffected, and hence there is no relocation of productive factors towards high-productive firms. Here, productivity effects arise at the firm-level due to adjustments in the assignment or workers to tasks. Thereby, it follows from Proposition 11 and 12 that the existence of labor market imperfections are instrumental for the impact of trade on firm productivity. With differences in the wage setting institutions among low-skilled and high-skilled workers, a higher labor demand in the open economy changes

[27] To see this, remember from (4.26), that $dw_h/dz > 0$.

[28] The reduction in the unemployment rate is also present in the Egger, Egger, and Markusen (2012) framework, where production consists of a single task performed by one type of workers. Similar to this chapter, the positive impact is a consequence of external scale economies in the production of the final good.

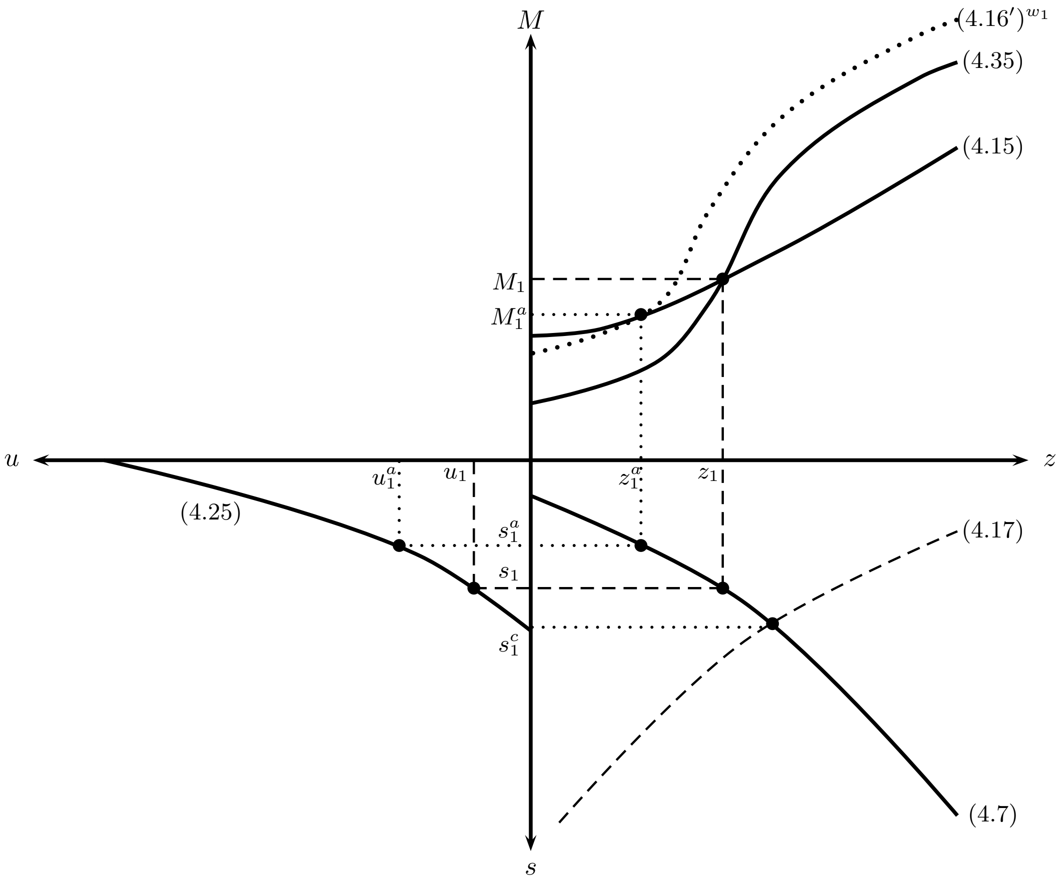


Figure 4.6: Trade between two fully symmetric minimum wage economies

the relative factor return and therefore leads to adjustments in the assignment of skills to tasks with consequences for a firm's labor productivity.[29]

## 4.4 Extensions

So far I have restricted the analysis to the comparison of open and closed economy equilibria. The aim of this Chapter is to shed light on how labor markets are linked in the open economy, i.e. how variations in national labor market institutions and endowments spill over to the partner country. I thereby focus on trade between two minimum wage economies as discussed in the previous chapter. Starting from a scenario with fully symmetric countries, I discuss how (i) an increase in Foreign's minimum wage for low-skilled workers and (ii) migration of high-skilled workers into the foreign economy, spill over to the domestic country.[30]

[29] I do not discuss endowment asymmetries here, as they are in the context of open minimum wage economies at the agenda of Chapter 4.4.2.

[30] From the discussion in the closed economy, I know that adjustments in $z$ and $M$ are only present if there is a change in the supply of high-skilled workers, while any change in $L$ is fully absorbed in the unemployment rate.

### 4.4.1 Minimum wage variations in the open economy

I start with a situation, in which the foreign country $j = 2$ adjusts its labor market institutions by increasing the minimum wage, such that $w_1 < w_2$ holds.[31] While the implications for country $j = 2$ are similar to these of the closed economy, the increase in $w_2$ implies $p_1(\phi^*) < p_2(\phi^*)$ according to (4.34) and a lower mass of firms in country $j = 2$. This reduction in the mass of intermediate goods producers now exerts an impact on the domestic country $j = 1$ according to (4.35). A smaller mass of producers in country $j = 2$, shifts locus (4.35) of country $j = 1$ leftwards in Figure 4.6, whereas it leaves loci (4.7), (4.15) and (4.17) and thus (4.25) unaffected. As a consequence, the range of tasks performed by low-skilled workers in country $j = 1$ must fall.[32] While the minimum wage for low-skilled workers is fixed in country $j = 1$, the factor return for high-skilled workers falls according to $w_h = w\alpha(z)$. Furthermore, since firms broaden the range of tasks performed by high-skilled workers, all active firms become more productive. However, increasing variable labor demand for high-skilled workers in the production process leaves less resources as a fixed input for firm entry. As a consequence, the mass of intermediate goods producers must fall in country $j = 1$. The adjustments in $M_1$ and $z_1$ imply a fall in the labor demand for low-skilled workers and the unemployment rate increases. Looking at the skill premium, high-skilled workers lose, but, according to (4.36), the reduction in $z$ increases relative per-capita income of high-skilled workers, due to an expansion of $L$-unemployment. The negative impact on the wage for high-skilled workers and the increase in the unemployment rate furthermore imply a reduction in welfare. These findings are summarized in the following proposition.

**Proposition 13** *Starting from an open economy equilibrium with minimum wages, an increase in the minimum wage in one country reduces the mass of firms and the range of tasks performed by low-skilled workers in the partner country, while it increases the productivity of active producers there. Low-skilled workers face a higher unemployment rate while high-skilled workers face a reduction in the real wage. The relative per-capita income of high-skilled workers increases, whereas welfare is reduced in the partner country.*

**Proof.** Analysis in the text and the formal proof in the appendix. ■

Interestingly, an implication of (4.33) and (4.34) is that minimum wages remain binding after opening up to trade and unemployment is persistent in both economies. In his seminal article, Davis (1998) concludes, that "international trade equalizes factor prices" (p.482), implying that only one minimum wage remains binding. This has been criticized by Egger, Egger, and Markusen (2012), using a model of heterogeneous firms where "productivity differences of marginal firms compensate for the prevailing wage differences" (p.774) such that minimum wages remain binding in both countries. In the Egger, Egger, and Markusen (2012) framework, trade changes the composition of active firms due to adjustments in the cutoff productivity. Moreover, if countries differ in their minimum wage, adjustments in the entry decisions of firms lead to $\phi_1^* \neq \phi_2^*$ and establish $p_1(\phi_1^*) = p_2(\phi_2^*)$. In my model, any adjustment in the cutoff productivity is closed since $\phi^*$ remains unaffected from changes in the minimum wage. In contrast, the firm-internal adjustment in the task-based production process allows firms to respond to changes in labor market institutions and therefore factor prices. The endogenous assignment of skills to tasks gives more flexibility to absorb differences in revenues, operating profits and fixed costs

Thus, I restrict the discussion to the interesting case where countries differ with respect to $H$ and therefore $z$, $s$ and $M$ in the closed economy.

[31]Comparing autarky with free trade between two countries that differ with respect to the minimum wage then follows from adding the insights from this chapter to the discussion in the previous one.

[32]In the appendix, I provide a formal prove of $dz_1/dw_2 < 0$ and $dz_2/dw_2 < 0$.

triggered by different labor market regimes. Hence, in my model a firms exogenous baseline productivity is the same in the two economies, but firms adjust their endogenous productivity part such that $\varphi(z_1) < \varphi(z_2)$ if $w_1 < w_2$.

### 4.4.2 Asymmetries in endowments

This chapter provides insights on how an increase in the supply of high-skilled workers in the foreign economy spills over to the domestic market. Starting from a symmetric equilibrium with minimum wages in both countries, the implications for country $j = 2$ of an increase in $H_2$ are similar to these of the closed economy, especially it results in a higher $z_2$ and $M_2$. The higher mass of intermediate goods producers in country $j = 2$, now exerts an impact on the domestic country $j = 1$, according to (4.35). The increase in $M_2$ shifts locus (4.35) of country $j = 1$ rightwards in Figure 4.6, whereas it leaves loci (4.7), (4.15) and (4.17) and thus also (4.25) unaffected. As a consequence, the range of tasks performed by low-skilled workers in country $j = 1$ must increase.[33] As less high-skilled workers are used as a variable input, which implies a fall in productivity of all active producers, more high-skilled workers are left to provide the input for the lottery and to manage the firm and organize the production process, thus $M_1$ increases. The increase in labor demand for low-skilled workers, triggered by the firm-internal adjustment of skills to tasks and additional firm entry, implies that the unemployment rate must fall in country $j = 1$. Looking at high-skilled workers, they experience an increase in the real wage. However, from inspection of (4.36), it follows that the increase in $z$ unambiguously reduces relative per-capita income $w_h/[(1-u)w]$. Furthermore, the increase in group-specific per-capita income levels $(1-u)w$ and $w_h$ provides a welfare stimulus in the domestic country. These findings are summarized in the following proposition.

**Proposition 14** *Starting from an open economy equilibrium with minimum wages in both countries, an increase in the supply of high-skilled workers in one country increases the mass of firms and the range of tasks performed by low-skilled workers in the partner country, and reduces productivity of active firms, there. Low-skilled workers face a lower unemployment rate, while high-skilled workers face an increase in the real wage which raises welfare in the partner country. Relative per-capita income of high-skilled workers falls in the partner country.*

**Proof.** Analysis in the text and the formal proof in the appendix. ■

## 4.5 Concluding remarks

This chapter sets up a heterogeneous firms model along the lines of Melitz (2003). However, the model accounts for a more sophisticated production process, in which a firm's output is microfounded using a continuum of tasks. Firms hire low-skilled and high-skilled workers for the performance of tasks. Tasks differ in their complexity and workers differ in their ability to perform these tasks, with high-skilled workers having a comparative advantage in performing more complex tasks. How firms organize the firm-internal production process by assigning skills to tasks depends on the respective factor costs and the productivity advantage of high-skilled workers in performing more complex tasks. Accounting for a task-based production process, allows me to discuss a so far unexplored adjustment margin, through which firms respond to exogenous shocks.

I use this framework to analyze how imperfections in the labor market affect the firm-internal assignment of skills to tasks in the closed economy. After characterizing the autarky equilibrium

[33] In the appendix, I provide a formal prove of $dz_1/dH_2 > 0$ as well as $dz_2/dH_2 > 0$.

outcome with fully flexible wages for both skill types, I introduce a (real) minimum wage, that is set by the government for low-skilled workers and causes involuntary unemployment of this skill type. As relative factor prices are changed and low-skilled task production becomes more costly, firms assign high-skilled workers to a broader range of tasks. This firm-internal skill upgrading improves a firm's labor productivity. However, as more high-skilled workers are employed for the performance of tasks, less of them are left to manage firms and the mass of firms therefore declines. Firm exit triggers a decline in aggregate output, income and welfare. After discussing migration of low-skilled and high-skilled workers under the two different labor market regimes, I use the model to discuss how trade between two countries affects the firm-internal production process. Only when low-skilled wages are set by a binding minimum wage, trade exerts an impact on the firm-internal assignment process. The opening up to trade raises demand for each firm due to a standard division of labor effect. When the factor price for low-skilled workers is fixed, the skill premium increases implying that high-skilled task production becomes relatively unattractive. Firms respond in broadening the range of task production with low-skilled workers, which reduces labor productivity of each firm. Aside from this negative productivity effect, trade increases the mass of producers in each country and reduces the unemployment rate of low-skilled workers. This causes an increase in per-capita income of both skill types, with high-skilled workers benefiting disproportionately. As a consequence aggregate output, income and welfare are stimulated. After discussing the movement from autarky to trade I show how changes in local endowments and labor market institutions spill over to the partner country. Thereby, I show that an increase in the minimum wage abroad reduces the range of tasks performed by low-skilled workers at home, while it increases the productivity of active producers, there. Both skill types end up with a lower per-capita income, and thus welfare is reducedat home.

The discussion in the main text abstracts from the fact that firms do also organize their production process geographically. With a task-based production function, firms clearly have an incentive to shift the production of tasks to countries with the lowest cost. In the absence of impediments to shift and transport tasks between countries, task trade would then lead to factor price equalization among the partner countries. Moreover, in contrast to the findings above, trade in tasks implies that only the minimum wage in the high wage country remains binding. As firms shift the production of tasks performed by low-skilled workers to the low minimum wage economy, this increases labor demand for that skill type there, and the incentive to shift tasks is present until the market clearing wage abroad is equal to the minimum wage at home. The outsourcing of low-skilled tasks would therefore increase the domestic unemployment rate. Moreover, to the extend that task trade also affects relative factor prices, firms will respond by adjusting the assignment of skills to tasks.

Clearly, to keep the analysis tractable, this framework relies on several simplifying assumptions. However, they help to concentrate on the firm-internal adjustment margin and how firms adjust their task-based production process, which is the focus of this chapter. By shedding light on this new, so far unexplored channel, I hope that my findings encourage further research on the organization of labor within firms.

## 4.6 Appendix

### Derivation of Eq. (4.11)

Aggregate revenues of all intermediate producers equal

$$R = M \int_{\phi^*}^{\infty} r(\phi) \frac{dG(\phi)}{1 - G(\phi^*)}. \tag{4.37}$$

Accounting for $r(\phi)/r(\phi^*) = (\phi/\phi^*)^{\sigma-1}$ and using the Pareto distribution for parameterizing $G(\phi)$, I can compute average revenues $\bar{r} = R/M$ as follows:

$$\bar{r} = r(\phi^*) \frac{k}{k - \sigma + 1} = \frac{\sigma k f w_h}{k - \sigma + 1}, \tag{4.38}$$

where the second equality follows from the fact that constant markup pricing implies $\pi(\phi) = r(\phi)/\sigma - f w_h$, while the marginal firm makes zero profits $\pi(\phi^*) = 0$. Therefore, average profits in the market, $\bar{\pi} = \bar{r}/\sigma - f w_h$, can be expressed as (4.11). *QED*

### Welfare effects of an increase in the supply of high-skilled workers

Substitution of (4.31) into (4.28) gives

$$W = \frac{\exp[\frac{1+z^2}{2}] \left(z \exp[z]\right)^{-\frac{1}{\sigma-1}}}{z(\sigma-1)(\exp[z]-1)+\sigma} \tilde{\zeta}, \tag{4.39}$$

where $\tilde{\zeta} \equiv \{L(k-\sigma+1)/[fk(\sigma-1)]\}^{(1)/(\sigma-1)} \sigma \zeta^{-1}$. Taking the derivative of (4.39) with respect to $z$, I can compute

$$\left.\frac{dW}{dz}\right|_{Eq.(4.39)} = W \left[ z - \frac{1}{\sigma-1} \frac{1+z}{z} - \frac{(\sigma-1)(\exp[z] + z\exp[z] - 1)}{z(\sigma-1)(\exp[z]-1)+\sigma} \right] \tag{4.40}$$

$$\left.\frac{dW}{dz}\right|_{Eq.(4.39)} = W \left[ \frac{\left(\sigma \exp[z] z - \sigma z - \exp[z] z + z + 1\right) \left(\sigma z^2 - \sigma - z^2 - \sigma z\right)}{z(\sigma-1)\left[z(\sigma-1)(\exp[z]-1)+\sigma\right]} \right]. \tag{4.41}$$

Noting that $\sigma z^2 - \sigma - z^2 - \sigma z < 0$, $\frac{dW}{dz}\big|_{Eq.(4.39)} < 0$ if $A(z) \equiv \sigma \exp[z] z - \sigma z - \exp[z] z + z + 1 > 0$. From $A(0) = 1$ and $A(1) = \sigma \exp[1] - \sigma - \exp[1] + 2 > 0$, together with $A'(z) = \sigma \exp[z] z + \sigma \exp[z] - \sigma - \exp[z] z - \exp[z] + 1$, where $A'(0) = \sigma(\exp[1] - 1)$¿0 and $A'(1) = 2\sigma \exp[1] - 2\exp[1] + 1 > 0$ and finally $A''(z) = (\sigma - 1)\exp[z](2 + z) > 0$, I can conclude that $A(z) > 0$ holds.

### Derivation details for Eq. (4.35)

Starting from $P = [M_j p_j(\tilde{\phi})^{1-\sigma} + M_{-j} p_{-j}(\tilde{\phi})^{1-\sigma}]^{1/(1-\sigma)}$ I can account for $P = 1$ to obtain $1 = M_j p_j(\tilde{\phi})^{1-\sigma} + M_{-j} p_{-j}(\tilde{\phi})^{1-\sigma}$. Noting that $p_j(\tilde{\phi}) = [w_{lj}\zeta]/\beta(z_j)$, according to (4.7) and (4.10), this can be rewritten as in (4.35). To show that (4.35) still establishes a positive link between $z_j$ and $M_j$ for given foreign values of $z_{-j}$ and $M_{-j}$, rewrite (4.35) as

$$M_j = \left(\frac{w_{lj}\zeta}{\beta(z_j)}\right)^{\sigma-1} \left\{ 1 + \frac{M_{-j}}{M_j} \left[ \frac{w_{lj}}{w_{l-j}} \frac{\beta(z_{-j})}{\beta(z_j)} \right]^{\sigma-1} \right\}^{-1} \tag{4.42}$$

and thus as

$$(w_{lj}\zeta)^{\sigma-1} = M_j\beta(z_j)^{\sigma-1} + M_{-j}\left[\frac{w_{lj}}{w_{l-j}}\beta(z_{-j})\right]^{\sigma-1}. \tag{4.43}$$

This allows me to define the implicit function

$$\Gamma(z_j, M_j) \equiv M_j\beta(z_j)^{\sigma-1} + M_{-j}\left[\frac{w_{lj}}{w_{l-j}}\beta(z_{-j})\right]^{\sigma-1} - (w_{lj}\zeta)^{\sigma-1}. \tag{4.44}$$

Applying the implicit function theorem to (4.44), gives me $dM_j/dz_j = -[\partial\Gamma(\cdot)/\partial z_j]/[\partial\Gamma(\cdot)/\partial M_j] = M_j(\sigma-1)(1-z_j) > 0$. *QED*

## Derivation details for Chapter 4.4.1

To discuss the implications of an increase in $w_2$ on $z_1$ and $z_2$ in the open economy, I can use (4.33) and define the implicit function[34]

$$\Gamma^1(z_1, z_2; w_1, w_2) \equiv \frac{w_1}{w_2} - \exp\left\{\frac{z_2 - z_1}{2}\left[2 - \frac{\sigma-1}{\sigma}(z_1 + z_2)\right]\right\} = 0. \tag{4.45}$$

To get a second relation between $z_1$ and $z_2$ as a function of the two minimum wages, I can evaluate (4.44) for country $j = 1$. Substituting $M_1$ and $M_2$ from (4.15) with $H_1 = H_2 = H$ and accounting for the definition for $\beta(z_1)$, I can thus define the implicit function

$$\Gamma^2(z_1, z_2; w_1, w_2) \equiv \frac{\exp\left[\frac{\sigma-1}{2}(1-z_1)^2\right]}{(1-z_1)(\sigma-1)+1} + \frac{\exp\left[\frac{\sigma-1}{2}(1-z_2)^2\right]}{(1-z_2)(\sigma-1)+1}\left(\frac{w_1}{w_2}\right)^{\sigma-1} - \frac{fkw_1^{\sigma-1}\zeta^{\sigma-1}}{H(k-\sigma+1)} = 0. \tag{4.46}$$

Applying the implicit function theorem to (4.45), (4.46) and accounting for $dw_1 = 0$, gives

$$\Gamma^1_{z_1}\frac{dz_1}{dw_2} + \Gamma^1_{z_2}\frac{dz_2}{dw_2} = -\Gamma^1_{w_2} \quad \text{and} \quad \Gamma^2_{z_1}\frac{dz_1}{dw_2} + \Gamma^2_{z_2}\frac{dz_2}{dw_2} = -\Gamma^2_{w_2}. \tag{4.47}$$

Applying Cramer's rule, I can calculate $dz_1/dw_2$ and $dz_2/dw_2$ according to

$$\frac{dz_1}{dw_2} = \frac{\Gamma^1_{z_2}\Gamma^2_{w_2} - \Gamma^1_{w_2}\Gamma^2_{z_2}}{|A|} \quad \text{and} \quad \frac{dz_2}{dw_2} = \frac{\Gamma^1_{w_2}\Gamma^2_{z_1} - \Gamma^1_{z_1}\Gamma^2_{w_2}}{|A|}, \tag{4.48}$$

with $|A| = \Gamma^1_{z_1}\Gamma^2_{z_2} - \Gamma^1_{z_2}\Gamma^2_{z_1}$. The respective partial derivatives are given by

$$\Gamma^1_{z_1} = \frac{w_1}{w_2}\left(1 - \frac{\sigma-1}{\sigma}z_1\right) > 0, \quad \Gamma^1_{z_2} = -\frac{w_1}{w_2}\left(1 - \frac{\sigma-1}{\sigma}z_2\right) < 0, \quad \Gamma^1_{w_2} = -\frac{w_1}{w_2^2} < 0,$$

$$\Gamma^2_{z_1} = \exp\left[\frac{\sigma-1}{2}(1-z_1)^2\right]\frac{\sigma-1}{[(1-z_1)(\sigma-1)+1]^2}[z_1 - (1-z_1)^2(\sigma-1)],$$

$$\Gamma^2_{z_2} = \exp\left[\frac{\sigma-1}{2}(1-z_2)^2\right]\frac{\sigma-1}{[(1-z_2)(\sigma-1)+1]^2}[z_2 - (1-z_2)^2(\sigma-1)]\left(\frac{w_1}{w_2}\right)^{\sigma-1},$$

$$\Gamma^2_{w_2} = -\exp\left[\frac{\sigma-1}{2}(1-z_2)^2\right]\frac{\sigma-1}{(1-z_2)(\sigma-1)+1}\left(\frac{w_1}{w_2}\right)^{\sigma-1}\frac{1}{w_2} < 0.$$

[34]In the interest of readability, I use $j = 1, 2$ in the subsequent derivations instead $j$ and $-j$.

The signs of $\Gamma^1_{z1}$, $\Gamma^1_{z2}$, $\Gamma^1_{w2}$ and $\Gamma^2_{w2}$ need no further discussion. To determine the sign of $\Gamma^2_{z_1}$ and $\Gamma^2_{z_2}$, note first that the requirement for a stable equilibrium is given by the same condition $z_j < \hat{z}$ – with $\hat{z}$ determined by (4.22) – in the closed as well as the open economy. Noting further that the sign of $\Gamma^2_{z_j}$ is determined by the sign of $g(z_j) \equiv z_j - (1-z_j)^2(\sigma-1)$, it follows from $g(0) = -(\sigma-1) < 0$, $g(\hat{z}) = 0$, and $g'(z_j) = 1 + 2(1-z_j)(\sigma-1) > 0$ that both $\Gamma^2_{z_1} < 0$ and $\Gamma^2_{z_2} < 0$ are negative in the relevant parameter domain.
Furthermore, given the sign for the partial derivatives, it is easily confirmed that $|A| < 0$ and $dz_2/dw_2 < 0$ hold. To determine the sign of $dz_1/dw_2$, I can calculate

$$\begin{aligned}
\frac{dz_1}{dw_2} &= \frac{1}{|A|}\exp\left[\frac{\sigma-1}{2}(1-z_2)^2\right]\frac{\sigma-1}{(1-z_2)(\sigma-1)+1}\left(\frac{w_1}{w_2}\right)^{\sigma-1}\frac{w_1}{w_2^2} \\
&\qquad \left[1-\frac{\sigma-1}{\sigma}z_2+\frac{z_2-(1-z_2)^2(\sigma-1)}{(1-z_2)(\sigma-1)+1}\right] \\
\frac{dz_1}{dw_2} &= \frac{1}{|A|}\exp\left[\frac{\sigma-1}{2}(1-z_2)^2\right]\frac{(\sigma-1)/\sigma}{[(1-z_2)(\sigma-1)+1]^2}\left(\frac{w_1}{w_2}\right)^{\sigma-1}\frac{w_1}{w_2^2}\left[\sigma+z_2(\sigma-\sigma z_2+z_2)\right],
\end{aligned}$$

and thus $dz_1/dw_2 < 0$, due to $|A| < 0$. *QED*

## Derivation details for Chapter 4.4.2

Consider $w_1 = w_2$. Then, (4.33) establishes the implicit function

$$\Gamma^3(z_1,z_2) \equiv 1 - \exp\left\{\frac{z_2-z_1}{2}\left[2-\frac{\sigma-1}{\sigma}(z_1+z_2)\right]\right\} = 0. \tag{4.49}$$

Furthermore, allowing for $H_1 \neq H_2$, I can substitute $M_1$ and $M_2$ from (4.15) into (4.44) and account for the definition of $\beta(z)$ to formulate the implicit function

$$\begin{aligned}
&\Gamma^4(z_1,z_2,H_1,H_2) \equiv \\
&\quad H_1\frac{\exp\left[\frac{\sigma-1}{2}(1-z_1)^2\right]}{(1-z_1)(\sigma-1)+1} + H_2\frac{\exp\left[\frac{\sigma-1}{2}(1-z_2)^2\right]}{(1-z_2)(\sigma-1)+1}\left(\frac{w_1}{w_2}\right)^{\sigma-1} - \frac{fkw_1^{\sigma-1}\zeta^{\sigma-1}}{k-\sigma+1} = 0.
\end{aligned} \tag{4.50}$$

Applying the implicit function theorem to (4.49), gives $dz_2 = -dz_1\Gamma^3_{z_1}/\Gamma^3_{z_2}$. Furthermore, applying the implicit function theorem to (4.50) and accounting for the previous result, allows me to calculate

$$\frac{dz_1}{dH_2} = -\frac{\Gamma^4_{H_2}}{\Gamma^4_{z_1} - \Gamma^4_{z_2}\Gamma^3_{z_1}/\Gamma^3_{z_2}}. \tag{4.51}$$

Accounting for $\Gamma^4_{H_2} > 0$, $\Gamma^4_{z_1} = H_1\Gamma^2_{z_1} < 0$, $\Gamma^4_{z_2} = H_2(w_1/w_2)^{1-\sigma}\Gamma^2_{z_2} < 0$, $\Gamma^3_{z_1} = \Gamma^1_{z_1}w_2/w_1 > 0$ and $\Gamma^3_{z_2} = \Gamma^1_{z_2}w_2/w_1 < 0$, it follows immediately that $dz_1/dH_2 > 0$. Moreover, with $dz_2 = -dz_1\Gamma^3_{z_1}/\Gamma^3_{z_2}$, $dz_2/dH_2 > 0$ holds. *QED*

# Chapter 5

# Conclusions

The purpose of this thesis was to analyze how globalization shapes the organization of production within firms, with a particular focus on the role of labor market imperfections in open economies. Chapter 2 has presented a general oligopolistic equilibrium model of MPFs and labor market imperfections due to union wage-setting in a subset of industries. This setting has been used to tackle two questions that have sparked considerable interest of economists in recent years and are of relevance for policy makers alike. The first question deals with firm-level (and related economy-wide) adjustments to deunionization, a phenomenon that has been observed in all industrialized countries over the last four decades. Associating deunionization with a reduction in the share of unionized industries, it has been shown that deunionization raises both the competitive and the union wage and thus renders a shortening of the product range attractive for MPFs. In addition to the decline in firm scope, the cost increase lowers total output of all interior varieties, so that firm scale decreases in unionized as well as non-unionized industries. With firms concentrating on high-competence varieties, deunionization therefore leads to an increase in labor productivity of all firms (except for the newly deunionized ones). The second question that has been tackled in this chapter is the impact of trade on firm scale and scope. In this respect, the main insight from the analysis is that, while firms become leaner and meaner as in models of MPFs without labor market frictions, the additional labor force that has been set free by the decline in firm scope is not equally allocated to unionized and non-unionized industries and thus it is not guaranteed that all firms actually increase their scale when being exposed to international trade. To be more specific, with labor market institutions being industry-specific, the firm-level effects of trade depend on a non-trivial interplay of product differentiation and the degree of unionization.

In Chapter 3 a model of heterogeneous firms along the lines of Melitz (2003) has been set up using a production process that builds on a continuum of tasks with differing skill requirements. Furthermore, it has been assumed that workers differ in their abilities to perform these tasks, and firms therefore face the complex problem of matching heterogeneous workers with heterogeneous tasks. To solve this allocation problem in a satisfactory way, firms require information about worker ability and they can get this information by screening their applicants. Screening involves fixed costs and provides an imprecise signal about the ability of workers. The higher the investment into the screening technology, the better is the signal and the better is therefore the match between abilities of workers and skill requirements of tasks. Intuitively, firms that have a higher ex ante productivity install a better screening technology, so that the heterogeneity of firms is reinforced by the endogenous investment into screening. This framework has been used to study the consequences of trade for welfare and underemployment, arising from the mismatch between workers and tasks. If only the best (most productive) firms self-select into exporting, trade exerts an asymmetric effect on the screening incentives of high- and low-productivity firms. High-productivity firms expand production due to exporting, and therefore find it attractive to install a better (more expensive) screening technology. In contrast, low-productivity firms do not export and lose market share at home. In response, they lower their screening expenditures. Despite this asymmetry in firm-level adjustments to trade, the average mismatch between worker-specific abilities and task-specific skill requirements unambiguously shrinks in the open economy. This points to a so far unexplored channel through which trade can improve the labor market outcome and stimulate welfare.

Chapter 4 has presented a heterogeneous firms model along the lines of Melitz (2003). However, the model accounts for a more sophisticated production process, in which a firm's output is manufactured using a continuum of tasks similar to the framework in the previous chapter. Firms hire low-skilled and high-skilled workers for the performance of tasks. Tasks differ in their complexity and workers differ in their ability to perform these tasks, with high-skilled workers having a comparative advantage in performing more complex tasks. How firms organize the firm-internal production process by assigning skills to tasks depends on the respective factor costs and productivity advantage of high-skilled workers in performing more complex tasks. This framework has been used to analyze how imperfections in the labor market affect the firm-internal assignment of skills to tasks in the closed economy. After characterizing the autarky equilibrium outcome with fully flexible wages for both skill types, a (real) minimum wage has been introduced. The minimum wage is set by the government for low-skilled workers and causes involuntary unemployment for that skill type. As relative factor prices are changed and low-skilled task production becomes more costly, firms assign high-skilled workers to a broader range of tasks. This firm-internal skill upgrading improves a firm's labor productivity. However, as more high-skilled workers are employed for the performance of tasks, less of them are left to manage firms and the mass of firms therefore declines. Firm exit triggers a decline in aggregate output, income and welfare. After discussing migration of low-skilled and high-skilled workers under the two different labor market regimes, the model has been used to discuss how trade between two countries affects the firm-internal production process. Only when low-skilled wages are set by a binding minimum wage, trade exerts an impact on the firm-internal assignment process. The opening up to trade raises demand for each firm due to a standard division of labor effect. When the factor price for low-skilled workers is fixed, the skill premium increases implying that high-skilled task production becomes relatively unattractive. Firms respond in broadening the range of task production with low-skilled workers, which reduces labor productivity of each firm. Aside from this negative productivity effect, trade increases the mass of producers in each country and reduces the unemployment rate of low-skilled workers. This causes an increase in aggregate output, income and welfare and widens the gap of high-skilled and low-skilled labor income. After discussing the movement from autarky to trade it has been shown how changes in local endowments and labor market institutions spill over to the partner country. Thereby, an increase in the minimum wage abroad reduces the range of tasks performed by low-skilled workers at home, while it increases the productivity of active producers there. Both skill types end up with a lower per-capita income, and thus welfare is reduced at home.

Of course, the organization of production has many different dimensions and this thesis cannot provide a comprehensive picture of all possible channels through which globalization and labor market imperfections may affect the organization of production. Moreover, to keep the analysis tractable, the different frameworks rely on several simplifying assumptions, which help to concentrate on the main issues that are focus of this thesis, such as adjustments in the product range or the assignment of workers to tasks in response to trade liberalization. By shedding light on these new, so far unexplored firm-internal adjustment margins, I hope that my findings encourage further research on the organization of firms.

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# Curriculum Vitae

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| 2002 | Abitur (A-levels), Dientzenhofer Gymnasium Bamberg (Germany) |
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