Firm-Level Technology Choices and Endogenous Production Structures in the Global Economy

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Preface

The economic integration of countries has always been at the heart of economic analysis. For more than a century and a half, the aim was to explain the emergence of trade patterns between countries as well as to study their impact on production structures and welfare. Within the last decades, the economic integration of countries and the analysis thereof broadened in several aspects. Moreover, recent developments in globalization have brought about a new level of international interaction beyond the mere exchange of final goods and services. First, innovations in communication and transportation technologies have massively facilitated to split up the value chain of production across different countries. Second, economies that have customized their regulatory framework to accommodate the inflow of foreign direct investment (FDI) and the adoption of innovative production techniques from the world technology frontier have been able to boost their total factor productivities (TFP). Third, trade, offshoring and the adoption of modern production technologies have heavily increased welfare across economies, while in most countries, wage differences between high- and low-skilled workers have substantially risen. More generally, the steep increase in the volume of FDI and the trade in intermediate inputs demanded new explanations of multinational firm activities and their impact on domestic and global production structures.

Globalization in recent decades has mainly been a firm-level phenomenon. Foremost, the intensified internationalization of firm activities led to the emergence of multinational enterprises (MNEs) that conduct a variety of operations in a range of different countries. Nevertheless, some firms across countries still produce and sell on a pure domestic scale. Moreover, the analysis of how globalization effects even pure domestic firms' technologies and reshapes production structures of MNEs requires a thorough understanding of firm-level choices in production. In essence, firms transform inputs into output by using a specific production technology. When not being constrained by exogenous restrictions, firms adopt optimally their production processes to output-specific factor requirements and factor prices. Economic theory has to consider the endogenous choice of firm-level technologies and production structures in the analysis of firm-level reactions to the integration of world economies.

This dissertation contributes to the economic analysis of the impact of globalization on firm-level choices in the production process. For this purpose, a novel concept of endogenous technology adoption is developed that provides new insights in the effects of world-wide economic integration on domestic firms. Furthermore, a novel framework is proposed that studies the optimal structure of value chains within and across countries .

Since empirical results of the impact of FDI on domestic firms' production techniques and productivity levels are mixed (Görg and Greenaway, 2004; Crespo and Fontoura, 2007), a thorough theoretical analysis is required. A guideline for the latter consists in two observations. First, MNEs are substantively more productive than domestic firms (Greenaway and Kneller, 2007). Second, the entry of foreign firms causes regularly an increase in a country's skill premium (Goldberg and Pavcnik, 2007). The first chapter analyzes the effects of increased factor market competition through the entry of MNEs on domestic firms' level of technology in production. For an analysis of the interaction of labor markets and firm-level technology choices, Acemoglu et al. (2007)'s model of endogenous technology choice is extended by the notion of technology being complementary to skills (Goldin and Katz, 1998). However, the use of sophisticated production techniques is restricted in many countries by barriers to technology adoption (Parente and Prescott, 1994, 2002). Moreover, also firms within a country differ largely in their productive use of technologies (Bernard and Jensen, 1995, 1999). The second chapter analyzes the impact of lower barriers to technology adoption on firm-level differences in production techniques via the labor market channel. In general, endogenous choices in production processes encompass the optimal structure of intermediate production stages and, on a global scale, the optimal structure of global value chains. In Costinot et al. (2011), a sequential global production process emerges endogenously where less productive countries concentrate on earlier intermediate production stages. However, modern production processes dispose of a variety of different structures which can be characterized by their sequential or parallel nature. The third chapter proposes an endogenous firm-level choice of the structure of production and analyzes the impact on global value chains.

The first chapter of my dissertation analyzes the impact of foreign firm entry on the endogenous technology choices of domestic firms. Empirical studies on the effects of MNEs' market entry on domestic firms' technology and productivity levels provide mixed results (Aitken and Harrison, 1999; Crespo and Fontoura, 2007; Greenaway and Kneller, 2007). The impact of FDI on a country's skill premium is however clear-cut: Higher levels of FDI increase the wage gap (Goldberg and Pavcnik, 2007). Since the use of technology in production is skill-complementary (Goldin and Katz, 1998), a rise in the skill premium implies higher technology adoption costs. This chapter provides an analysis of the impact of MNEs' market entry on the technology choices of domestic firms via the labor market channel.

For this purpose, I develop a tractable model that extends Acemoglu et al. (2007)'s approach of modeling a firm's technology choice as the optimal degree of specialization in production by two aspects. First, I introduce skill-complementarity of technology that involves feedback effects of aggregated demands of high- and low-skilled labor on firm-level technology choices. In particular, intermediate inputs in a firm's production process are produced within the firm and differ with respect to their high-skill intensity (Feenstra and Hanson, 1997). In my model, an increase in the endogenous level of technology involves to add intermediate inputs that are relatively more high-skill intensive than intermediates required for less sophisticated production techniques. With symmetry among firms, a higher level of technology in production thus rises aggregated relative skill demand and implies a higher skill premium. Second, I introduce differences in the degree of gains from technology in production across firms. In particular, MNEs use technology in production more efficiently than domestic firms which results in a higher productivity of the former (Doms and Jensen, 1998; Greenaway and Kneller, 2007). Moreover, domestic and foreign firms enter the economy endogenously where MNEs face higher market entry costs than local firms (Aghion et al., 2009). Whether foreign as well as domestic firms enter the economy depends in essence on the relation of MNEs' advantage in the use of technology in production to domestic firms' advantage in lower market entry costs. The main finding of this chapter is that the entry of MNEs increases the competition for skilled workers, rises the skill premium, and forces domestic firms to downgrade their levels of technology in production.

The second chapter of my dissertation studies the impact of lower barriers to technology adoption on endogenous technology choices of heterogeneous firms. Empirical studies (Caselli and Coleman, 2006; Gancia et al., 2011) emphasize the importance of barriers to technology adoption in explaining cross-country TFP differences. There exists a variety of anecdotal evidence of firm-level restrictions on the adoption of sophisticated production techniques (Parente and Prescott, 2002). Moreover, firms are heterogeneous with respect to productivity (Bernard and Jensen, 1995, 1999) such that some firms' optimal production techniques are more sophisticated than others'. Technology is further skill-complementary (Goldin and Katz, 1998) and the skill premium increases along with a greater openness of the country (Goldberg and Pavcnik, 2007) which typically involves lower barriers to technology adoption. This chapter analyzes the impact of lower barriers to technology adoption on differences in technology choices of heterogeneous firms with a particular focus on the labor market.

For this purpose, I extend the concept of skill-complementary technology choices on the firm-level, developed in the first chapter, by barriers that preclude the adoption of the most sophisticated production techniques. Since firms differ in their use of technology in production, barriers to technology adoption restrain in particular the most productive firms from adopting their optimal level of technology in production. If barriers decrease, more sophisticated production technologies become available which are primarily adopted by the more productive firms that were constrained beforehand. Since technology is skill-complementary, an upgrade in production techniques of some firms results in an increase in aggregated relative skill demand which raises the skill premium. In this vein, a higher wage gap increases technology adoption costs of less productive and by the barrier not restricted firms and forces them to downgrade their production techniques. This chapter shows that the endogenous technology gap between more and less productive firms sharply increases when barriers to technology adoption are lowered. Nevertheless, in line with e.g. Caselli and Coleman (2006) and Gancia et al. (2011), smaller barriers increase a country's overall welfare.

The third chapter of my dissertation is joint work with Carsten Eckel. We develop an elementary theory of endogenous production structures that provides novel insights in firm-level production decisions and their impact on global value chains. Manufacturing processes regularly consist of a large number of intermediate production stages which are regularly segmented across firms in different countries (Hummels et al., 2001). In a recent contribution, Costinot et al. (2011) analyze the endogenous specialization of countries in different stages of a sequential global value chain. In particular, countries with a higher probability of making mistakes specialize in earlier production stages while countries with lower failure rates focus on later stages. In this respect, the probability of making mistakes in production is a general measure of a country's productivity. However, disparities in value added at different intermediate stages imply that sequential production structures are not necessarily optimal. This chapter analyzes endogenous production structures within and across countries and focuses in particular on the impact of intermediates' value added and country-specific probabilities of making mistakes.

For this purpose, we consider two intermediate production stages to produce a final good where each intermediate step faces a country-specific probability of failure (Costinot et al., 2011). Moreover, each intermediate production stage has a particular labor requirement which represents its specific value added. At the beginning of each production process, the first intermediate stage is carried out. Subsequent to completion, the intermediate is either processed in a consecutive production stage, facing the country-specific probability of failure. Or, it is combined with a second intermediate input that was completed in a separate process subject to the country-specific failure rate. While we denote the former process as sequential, the latter is labeled parallel. Both approaches yield the same final good and require the same value added at the first and second intermediate production stages. Moreover, in parallel production, the final product is assembled without any labor costs, but subject to a particular probability of making mistakes. Whether a sequential or parallel production structure is optimal depends on the trade-off between the value added at loss within sequential structure's second step versus the risk of losing both intermediates during assembly. Embedding firms' choices into a closed economy shows that countries with higher probabilities of making mistakes choose a parallel production structure for lower value added at the first stage. In open economy, countries differ with respect to their labor endowments and the probability of making mistakes, where the latter reflects country-level differences in TFP. This chapter shows that Costinot et al. (2011)'s sequential global value chain emerges if value added of the first intermediate stage does not surpass a threshold. Countries with lower failure rates specialize in later stages of the global production process which involves Ricardian comparative advantages between economies. If first step's value added is great compared to the failure rate, welfare gains of Ricardian specialization are smaller than the potential loss at the second stage. In this case, parallel production structures emerge and specialization of economies on intermediate stages does not occur.

All three chapters of this dissertation are self-contained and include their own introductions and appendices such that they can be read independently.

Chapter 1

Do Multinationals Constrain Local Firms' Technology Adoption?

1.1 Introduction

The effects of multinational firm entry on domestic firms and industries are at the heart of a long-going debate about globalization and the liberalization of foreign direct investment (FDI). Particularly in countries that are laggards in terms of production technologies and productivity there exists a widespread desire to attract investments of multinational enterprises (MNEs). Their entry is supposed to induce knowledge spillovers to domestic firms as well as to foster competition on output and factor markets. However, the empirical literature provides mixed effects of foreign firm entry on domestic firms' technology and productivity levels[1]. In contrast, there exists widespread agreement that FDI inflows increase the demand of high-skilled labor and lead to a rise in the skill premium[2]. Since FDI is primarily carried out by the most productive firms and MNEs are usually from countries close to the world technology frontier, MNEs use more productive technologies than domestic firms[3]. Moreover, the adoption of more sophisticated production techniques

[1]See e.g. Aitken and Harrison (1999), Javorcik (2004), Aghion et al. (2009), and, for literature surveys, Sinani and Meyer (2004), Görg and Greenaway (2004), Crespo and Fontoura (2007).

[2]See e.g. Feenstra and Hanson (1997) and, for a literature survey, Goldberg and Pavcnik (2007).

[3]See e.g. Doms and Jensen (1998), Dimelis and Louri (2002), Proença et al. (2002), Torlak (2004) for MNEs' productivity advantage over domestic firms, Castellani and Zanfei (2007), Helpman et al. (2004) for evidence on firm-level productivity and FDI and, for a literature survey, Greenaway and Kneller (2007).

requires regularly a higher skill-level of the workforce[4], such that the entry of MNEs increases a country's aggregated high-skilled labor demand and the skill premium. Even though being rarely in the focus of policy makers, the impact of FDI on domestic labor markets and the consequences for domestic firms' production techniques clearly deserves closer attention.

This study is to the best of my knowledge the first to analyze the impact of foreign firm entry on the technology choices of domestic firms via the labor market channel. The entry of MNEs increases competition for skilled workers, rises the skill premium, and forces domestic firms to downgrade their levels of technology in production. With free entry, multinationals' advantage in technology relative to their disadvantage in market entry costs determines if they enter the domestic market and whether domestic firms are crowded out[5]. My theoretical study emphasizes the labor market effects of FDI on domestic firms' technology choices and analyzes the respective entry decisions of MNEs and domestic firms, while abstracting from other impact channels.

For this purpose, I develop a tractable model of skill-complementary endogenous technology choice. Following Acemoglu et al. (2007), a firm chooses endogenously its level of technology in production. The latter is modeled as the number of intermediate inputs in production and augments output on the firm-level as in Felbermayr and Jung (2011). While most studies that consider the degree of specialization in production assume symmetry among intermediates (Ethier, 1982; Benassy, 1998; Acemoglu et al., 2007; Eckel, 2008), I introduce heterogeneity with respect to intermediates' skill-intensity in production as in Feenstra and Hanson (1997). Furthermore, the production process is vertically integrated such that intermediate inputs and the final good are produced within the firm. As a consequence, the adoption of more sophisticated production techniques requires the production of intermediates that are relatively more skill intensive. This implies that producing output with a more sophisticated technology comes at the cost of employing relatively more of the more expensive factor, i.e. high-skilled labor. In this vein, a firm's production process directly links a firm's endogenous technology choice to its relative de-

[4]See e.g. Goldin and Katz (1998), O'Mahony et al. (2008), Lewis (2011).

[5]See e.g. Aghion et al. (2009) for different market entry costs of foreign firms. See Kosová (2010) for crowding out of domestic firms.

mand of skilled workers. In general equilibrium, the production-inherent cost structure of technology relates the endogenous technology level of firms to a country's skill premium.

Firms differ in general with respect to their scope for technology in production. In particular, the capability of using sophisticated production techniques more efficiently implies the choice of a higher level of technology in production and results in a higher productivity. Multinational firms, being based in countries closer to the technology frontier and having a global expertise, are usually endowed with a technological advantage over domestic firms. They choose more sophisticated production techniques and, complementary, hire a more skilled labor force. Moreover, this model assumes that multinationals set up a production unit in the host country, hire exclusively local workers, and sell the entire output in the host country's market. Whereas the latter assumption does not restrict the scope of the model, the former implies that foreign firm entry increases aggregated relative demand of high-skilled workers. However, as supplies of high- and low-skilled labor are fixed within a country, labor market clearing implies an increase in the skill premium. This directly raises technology adoption costs for all firms and forces domestic firms to downgrade their level of technology in production.

While MNEs profit from a greater scope for technology in production, they face higher market entry costs than domestic firms[6]. They regularly have to overcome greater bureaucratic hurdles, invest more to gather information on market-specific knowledge, or simply face institutional restrictions. In this vein, autarky mirrors a situation where the fixed costs disadvantage of MNEs outweighs their technological advantage such that they refrain from entering the domestic economy. In contrast, domestic firms may become completely crowded out if their smaller market entry costs do not compensate for coping with a toughened factor market competition from technologically more sophisticated multinationals. Given MNEs and domestic firms enter the market, their numbers depend on the trade-off between gains from technology in production and relative market entry costs. In this case, the autarkic relation of relative skill endowments to the wage gap is replaced by a correspondence of relative productivities to relative market entry costs. Hence, the extend of domestic firms' technology downgrades is determined by the relation

[6] Note that I use the terms market entry costs and fixed costs interchangeably throughout this chapter since there exists only one type of fixed costs for MNEs and domestic firms, respectively, which is paid at market entry.

of relative fixed costs to the difference in the scope for technology, since the latter drives the gap between productivities.

There exists a rich empirical literature on the effects of MNEs' market entry on domestic firms' technology and productivity levels. See e.g. Görg and Greenaway (2004) and Crespo and Fontoura (2007) for extensive literature surveys. However, empirical studies provide evidence on positive as well as on negative effects of foreign firm entry. For Venezuelan data, Aitken and Harrison (1999) find that an increase in FDI leads to a decline in domestic firms' productivities. Aghion et al. (2009) present empirical evidence from the United Kingdom that emphasizes the existence of differential impacts of foreign firm entry on domestic producers: Advanced domestic industries gain in productivity growth while laggard industries face a decline. Haskel et al. (2007), also using data from the United Kingdom, show a positive correlation between a domestic firms's total factor productivity and the share of foreign firms in that firm's industry. Kosová (2010) presents evidence from the Czech Republic that FDI results in a short-term crowding out of domestic firms as well as in technology spillovers to domestic firms.

In this chapter, the exclusive purpose of FDI is to serve the local market. Using data from Chinese firms, Li et al. (2001) show that there exist mainly negative spillovers to domestic firms through increased competition if FDI aim at producing for the domestic market. In a different approach, Javorcik (2004) finds evidence that the productivity of Lithuanian firms is positively correlated with contacts of foreign affiliates to their local suppliers. They find however no evidence that the presence of MNEs in the same industry or the existence of multinational suppliers of intermediate inputs leads to knowledge-spillovers.

Moreover, the focus of this chapter is on the impact of FDI on domestic firms' technology and productivity levels via the labor market channel. There exist several empirical studies that emphasize the increase in domestic high-skilled wages through the entry of foreign firms. In a seminal contribution, Feenstra and Hanson (1997) show that a growth in FDI flows towards Mexico raises the demand for high-skilled labor and increases its relative wage. Lorentowicz et al. (2008) provide evidence from Poland that high-skilled local workers gain from outsourcing towards their country. Goldberg and Pavcnik (2007) present an extensive literature survey on how globalization effects wage inequalities and show that most studies agree on a positive correlation. Using a cross-country analysis of more than 100 countries, Figini and Görg (2011) show that within developing countries the wage inequality increases with the stock of FDI. Sinani and Meyer (2004) point to a negative labor market effect of foreign firm entry on domestic firms. Their claim is that MNEs may headhunt the best workers (in general the more skilled) of domestic producers by offering higher wages than local firms.

This chapter of my dissertation relates to two different strands of the theoretical literature. First, this study contributes to a growing theoretical literature on the impact of FDI on host country's technology and productivity levels. For an analysis of the motivation of multinational firms to conduct FDI and of FDI's specific purposes, I refer to the extensive literature on horizontal FDI that emerged in the sequel of Markusen (1984) and is reviewed by Markusen and Maskus (2001). In general, theoretical studies on the impact of MNEs' entry on local economies can be distinguished by their focus on either the country- or the firm-level consequences. A contribution to the former is Müller and Schnitzer (2006)'s analysis of the incentives of a multinational firm and the host country to engage in international joint ventures that may imply technology transfers. However, my approach abstracts from knowledge-spillovers in order to focus on the impact on domestic firms through the factor market channel[7]. An early contribution to the literature on the effects of FDI on domestic firms is Rodríguez-Clare (1996)'s analysis. Spillovers of foreign affiliates increase the productivity of domestic firms via an increased access to specialized varieties of intermediate inputs while MNEs' affiliates may replace domestic firms. Kosová (2010) builds a model that separates the impacts of MNEs on domestic firms into a negative crowding out and a positive technology-spillover effect. Aghion et al. (2006) build a Schumpeterian style growth model that predicts an increased productivity growth in advanced domestic industries and decreased productivity growth in laggard industries if MNEs enter. However, their focus is on productivity growth and firms compete for shares on output markets. While the last two studies take into account productivity effects on the firm-level, they neglect in particular the endogenous choice

[7]See e.g. Bjorvatn and Eckel (2006) for a an analysis that considers technology spillovers in a firm's choices on FDI. There exists also an extensive macroeconomic literature on the virtues of FDI. See e.g. McGrattan and Prescott (2009)'s growth model where a country's productivity and welfare increase through FDI.

of production techniques and the impact of competition on factor markets. My model contributes to this literature by analyzing the impact of MNEs' entry on domestic firms' technologies via the labor market channel. In particular, the market entry of MNEs increases competition for high-skilled labor and rises the skill premium. Since technology is skill-complementary, a higher wage gap induces domestic firms to downgrade their levels of technology in production.

Second, the layout of my production function contributes to the literature on endogenous technology adoption. The basic set-up of my model is closest to Acemoglu et al. (2007)'s complete contract case. As in their paper, the level of technology in production is endogenously chosen and depends on the degree of gains from specialization. My model introduces complementarity of technology and high-skilled labor by assuming heterogeneity across intermediate inputs with respect to skill intensity. As a consequence, an increase in the endogenous level of technology involves to add intermediate inputs that are relatively more high-skill intensive than intermediates required for less sophisticated production techniques. Moreover, my model introduces differences across firms in the degree of gains from technology in production. In particular, MNEs gain more from the use of technology in production than domestic firms, resulting in a productivity advantage of the former.

In the following, firm-level production and profit maximization are introduced in *Section 1.2*. A firm's optimal choices of the level of technology and the quantities of intermediates in production as well as the corresponding demands of high- and low-skilled labor are presented in *Section 1.3*. The previous outcomes are then embedded in an autarkic economy in *Section 1.4*. The analysis of the impact of multinational firms' entry on domestic firms' choices is provided in *Section 1.5*. *Section 1.6* briefly concludes.

1.2 The Model

1.2.1 Firm-Level Production

Each firm i produces output Y_i according to the generalized C.E.S. production function

$$Y_i := N_i^{\kappa_i+1}\left(\frac{1}{N_i}\int_0^{N_i} x_{i,j}^{\frac{\sigma}{1+\sigma}}dj\right)^{\frac{1+\sigma}{\sigma}}. \tag{1.1}$$

A firm i chooses the level of technology in production, N_i[8], as well as the input quantity of each intermediate input, $x_{i,j}$. In particular, there exists an infinite amount of different intermediate inputs, $j \in [0,\mu]$ with $\mu \gg 1$, out of which a firm chooses optimally the subset $[0, N_i]$ where $N_i \leq \mu$[9].

An important determinant of N_i is a firm's scope for technology $\kappa_i > 0$, i.e. its technology type, that captures the extent to which a firm's production benefits from the level of technology. Whenever there is no loss of clarification, I will abstract from the firm index i to save on notation. Similar to standard models with C.E.S. production, $\sigma \in (0,\infty)$ determines the elasticity of substitution between different intermediate inputs in production, $1+\sigma > 1$. The elasticity of output with respect to the endogenously chosen N depends on the production function of intermediates. Evaluated at the optimum, the elasticity becomes $1-\kappa\sigma$. I impose $\kappa\sigma < 1$ to ensure a positive choice of N[10].

A simple decomposition of (1.1) provides an intuition of how technology and intermediate inputs interact in the production process. N^κ represents the contribution of the level of technology to the production of output where a higher κ increases the efficiency

[8] N_i is a measure of the number of different inputs used in production. In Acemoglu et al. (2007), it accounts for the variety of intermediate suppliers and represents a measure of technology that augments production. In Felbermayr and Jung (2011), higher input diversity implies a better fit of inputs in production.

[9] *Proposition 1.5* provides a condition for $N_i \leq \mu$. Note also that the assumption of an upper limit to technology, $0 \ll \mu < \infty$, is necessary to ensure that Cobb-Douglas exponents in (1.2) are in $[0,1]$.

[10] According to Felbermayr and Jung (2011), standard CES functions as in Melitz (2003) and Krugman (1980) implicitly assume $\kappa\sigma = 1$ while Ardelean (2007) shows that $0 < \kappa\sigma < 1$. In my model, $\frac{\partial Y}{\partial N}$ ((A1.4) in *Appendix 1.7.3*) implies that the elasticity of Y with respect to N depends on the production function of $x_{i,j}$. Evaluated at the optimum, the elasticity equals $1-\kappa\sigma$. An increase in κ dampens the elasticity at the profit maximizing level of technology. The restriction $\kappa\sigma < 1$ ensures a positive elasticity of Y with respect to N at the optimum. Thus, output reacts less to a change in the level of technology than in Acemoglu et al. (2007)'s set-up as intermediates are produced heterogeneously. See *Appendix 1.7.1* for a brief review of Acemoglu et al. (2007)'s optimal technology choice and how it differs from mine.

of technology in the production process. N accounts for the number of different intermediates. $\left(\frac{1}{N}\int_0^N x_j^{\frac{\sigma}{1+\sigma}}dj\right)^{\frac{1+\sigma}{\sigma}}$ constitutes an average quantity of intermediate inputs that are weighted by their degree of substitutability and results from netting the number and technology components.

Each intermediate input $j \in [0, N]$ is produced according to a generalized Cobb-Douglas function

$$x_j(L_j, H_j) := z_j L_j^{1-\frac{j}{\mu}} H_j^{\frac{j}{\mu}} \tag{1.2}$$

where $z_j \equiv \left(\frac{j}{\mu}\right)^{-\frac{j}{\mu}} (1-\frac{j}{\mu})^{-(1-\frac{j}{\mu})}$, H_j is the input quantity of high-skilled and L_j that of low-skilled labor. Total employment in each firm is given by $L \equiv \int_0^N L_j dj$ and $H \equiv \int_0^N H_j dj$. Given (1.2), I derive in *Appendix 1.7.2* minimum unit costs of producing one unit of j,

$$k_j = w_L \bar{w}^{\frac{j}{\mu}}, \tag{1.3}$$

where $\bar{w} \equiv \frac{w_H}{w_L}$ is the wage gap between high- and low-skilled labor. The formulation of the Cobb-Douglas production function in (1.2) is inspired by Antras (2005). The modification z_j corrects for the fact that standard Cobb-Douglas functions imply a change in productivity as j varies even if both inputs *were* equally expensive[11]. I adopt (1.2) to obviate these distortions in intermediate inputs' productivities.

The production function of an intermediate (1.2) imposes also a plausible relation between the productivity of skills and technology. In particular, L_j (H_j) is relatively less (more) productive in producing intermediate j' as it is in producing intermediate input j for $j' > j$[12]. As a consequence, a production process with a higher level of technology requires the use of increasingly high-skill intensive intermediate inputs. Put differently, the absolute technical rate of substitution $|TRS(H_j, L_j)| = |\frac{dL_j}{dH_j}| = \frac{\partial x_j}{\partial H_j} / \frac{\partial x_j}{\partial L_j}$ is increasing in j:

$$\frac{\partial |TRS(H_j, L_j)|}{\partial j} = \frac{\partial \left(\frac{\partial x_j}{\partial H_j} / \frac{\partial x_j}{\partial L_j}\right)}{\partial j} = \frac{L_j}{H_j} \frac{\frac{1}{\mu}}{(1-\frac{j}{\mu})^2} > 0.$$

[11]Productivity is measured by the inverse of minimum unit costs. In general equilibrium, high-skilled wages are always greater than low-skilled wages since production-augmenting technology is skill-complementary.

[12]Similar to Feenstra and Hanson (1997), intermediate inputs are arranged such that for higher j's, production is more high-skill intensive.

1.2.2 The Firm's Problem

Each firm maximizes its profit given wages (w_H, w_L) and market size (A),

$$\Pi\left(N, \{L_j\}_0^N, \{H_j\}_0^N\right) = A^{1-\beta}Y^\beta - C(Y) = A^{1-\beta}Y(H,L)^\beta - \int_0^N \left[w_H H_j + w_L L_j\right] dj,$$

where $A^{1-\beta}Y^\beta = pY$ is a firm's revenue derived from household demand of each firm's final good in a standard monopolistic competition framework. Household demand is given by (1.17) for domestic firms in autarky and by (1.24) for domestic firms and (1.25) for multinationals in open economy. Note that I do not distinguish between multinational and domestic firms in the firm-level analysis, except if explicitly stated. The measure of market size, A, and wages are endogenously determined in general equilibrium and β determines the elasticity of demand, $1/(1-\beta)$. $C(Y)$ are the production costs of Y that consist exclusively of expenditures for high- and low-skilled labor.

Profit maximization requires the firm to choose the optimal quantities of H_j and L_j within the production of each intermediate. This implies labor costs for each intermediate input of $w_H H_j + w_L L_j = k_j x_j$. The specification of intermediate inputs' production function replaces general minimum unit costs k_j by the specific unit costs $w_L \bar{w}^{\frac{j}{\mu}}$ (1.3) in a later step. Applying the concept of minimum unit costs, the firm's problem[13] becomes

$$\max_{N,\{x_j\}_0^N} \Pi\left(N, \{x_j\}_0^N\right) = \max_{N,\{x_j\}_0^N} \left\{A^{1-\beta}Y(N,\{x_j\}_0^N)^\beta - \int_0^N k_j x_j dj\right\}. \tag{1.4}$$

1.3 Technology in Production

1.3.1 Optimal Technology Choice

General solution

Each firm maximizes its profit (1.4) given minimum unit costs and market size. I impose $(\partial k_j)/(\partial j) > 0$ for a finite choice of technology level N[14]. The first order maximization

[13] The constraint $N \leq \mu$ is not considered at this stage, but it is shown in *Proposition 1.5* that there exist restrictions on parameters that ensure $N \leq \mu$.

[14] $(\partial k_j)/(\partial j) > 0$ results from the production function of tasks.

conditions determine simultaneously the optimal choice of technology [15] and the optimal quantity of intermediate inputs:

$$N: \qquad \kappa = \underbrace{\left(N\frac{\partial \bar{K}_N}{\partial N}\right)/\bar{K}_N}_{\equiv \varepsilon_{\bar{K}_N}}, \tag{1.5}$$

$$x_j \quad \forall j \in [0,N]: \qquad x_j = \beta^{\frac{1}{1-\beta}} A N^{\frac{\beta(\kappa+1)-1}{1-\beta}} \bar{K}_N^{\sigma-\frac{\beta}{1-\beta}} k_j^{-1-\sigma}. \tag{1.6}$$

The derivation of first order conditions is delegated to *Appendix 1.7.3.* The elasticity $\varepsilon_{\bar{K}_N}$ captures the change in average unit costs $\bar{K}_N$ when the level of technology increases. More precisely, $\bar{K}_N \equiv \left[\frac{1}{N}\int_0^N k_j^{-\sigma} dj\right]^{-\frac{1}{\sigma}}$ are the costs to produce the average intermediate input $\left(\frac{1}{N}\int_0^N x_j^{\frac{\sigma}{1+\sigma}} dj\right)^{\frac{1+\sigma}{\sigma}}$. Aggregation of the optimal x_j given in (1.6) (see *Appendix 1.7.3*) shows that $N\bar{K}_N \left(\frac{1}{N}\int_0^N x_j^{\frac{\sigma}{1+\sigma}} dj\right)^{\frac{1+\sigma}{\sigma}} = C(Y)$, i.e. the number of different intermediates times the average unit costs times the average quantity of intermediates equals total production costs. In optimum, the level of technology in production (1.5) is given by a trade-off between the degree of gains from technology (κ) and the elasticity of costs implied by the level of technology N ($\varepsilon_{\bar{K}_N}$). Assume e.g. that a firm is endowed with a high technology type. As the latter implies that technology is very productive the firm will choose a high level of N in production. This, in turn, increases the elasticity of average unit costs (see *Appendix 1.7.4*) such that (1.5) holds.

Optimal choices of the level of technology in production and the quantities of intermediate inputs results in the firm's optimal output (see *Appendix 1.7.3*),

$$Y = \beta^{\frac{1}{1-\beta}} A N^{\frac{\kappa}{1-\beta}} \bar{K}_N^{-\frac{1}{1-\beta}}. \tag{1.7}$$

It depends directly and indirectly (through $\bar{K}_N$) on the level of technology and, in combination with household demand ($Y = Ap^{\frac{1}{\beta-1}}$), implies a firm's price of the final good,

$$p = \frac{\bar{K}_N}{N^\kappa \beta}. \tag{1.8}$$

Note that the price is independent of output as neither N nor $\bar{K}_N$ depend on output.

[15] Note that the implicit equation that determines N can be written as $\bar{K}_N = k_N (1-\kappa\sigma)^{\frac{1}{\sigma}}$.

Furthermore, as in a standard monopolistic framework, the price is determined as marginal costs over β. Total production costs, evaluated at the optimum, can be expressed in terms of output as $C(Y) = \frac{Y\bar{K}_N}{N^\kappa} = \beta p Y$.

Solution given Cobb-Douglas production of intermediate inputs

The production function of intermediates in (1.2) allows a more detailed understanding of how gains from technology interact with the (in general equilibrium endogenous) wage gap in affecting a firm's choice of technology in production. For the following firm-level analysis that uses Cobb-Douglas production of intermediates, I impose $e^{\kappa\mu} > \bar{w} > e^{\frac{2\kappa}{1-\kappa\sigma}}$[16] to ensure an endogenous choice of technology within $(1, \mu]$. As $e^{\frac{2\kappa}{1-\kappa\sigma}} > e^{\kappa\beta}$, $\bar{w} > e^{\frac{2\kappa}{1-\kappa\sigma}}$ implies also positive high- and low-skilled firm-level labor demands.

In particular, minimum unit costs to produce intermediate input j are $k_j = w_L \bar{w}^{\frac{j}{\mu}}$, allowing to rewrite average unit costs into $\bar{K}_N = w_L \left(\frac{1}{N} \int_0^N \bar{w}^{-\sigma\frac{j}{\mu}} dj \right)^{-\frac{1}{\sigma}} = w_L \left(\frac{\bar{w}^{-\sigma\frac{N}{\mu}} - 1}{\frac{N}{\mu}(-\sigma)\ln\bar{w}} \right)^{-\frac{1}{\sigma}}$. Applying the latter in combination with minimum unit costs of the marginal intermediate, $k_N = w_L \bar{w}^{\frac{N}{\mu}}$, in (1.5), the *optimal choice of* N is obtained as an implicit function of the wage gap[17]:

$$\kappa = \underbrace{\frac{1}{\sigma} - \frac{\frac{N}{\mu}\ln\bar{w}}{\bar{w}^{\sigma\frac{N}{\mu}} - 1}}_{=\varepsilon_{\bar{K}_N}}. \tag{1.9}$$

The technology type as well as the elasticity of substitution between intermediates impact the chosen level of technology. In contrast, the optimal N is independent of the size of the market (A) and of the degree of "market competition" as measured by the elasticity of substitution between different products (β). Furthermore, as technology is proportionally chosen to the upper bound of the interval $[0, \mu]$, the following analysis does not contain comparative static with respect to μ. Note that although technology is in essence a function of the skill premium, $\bar{w}$, I use for convenience N instead of $N(\bar{w})$ throughout this study.

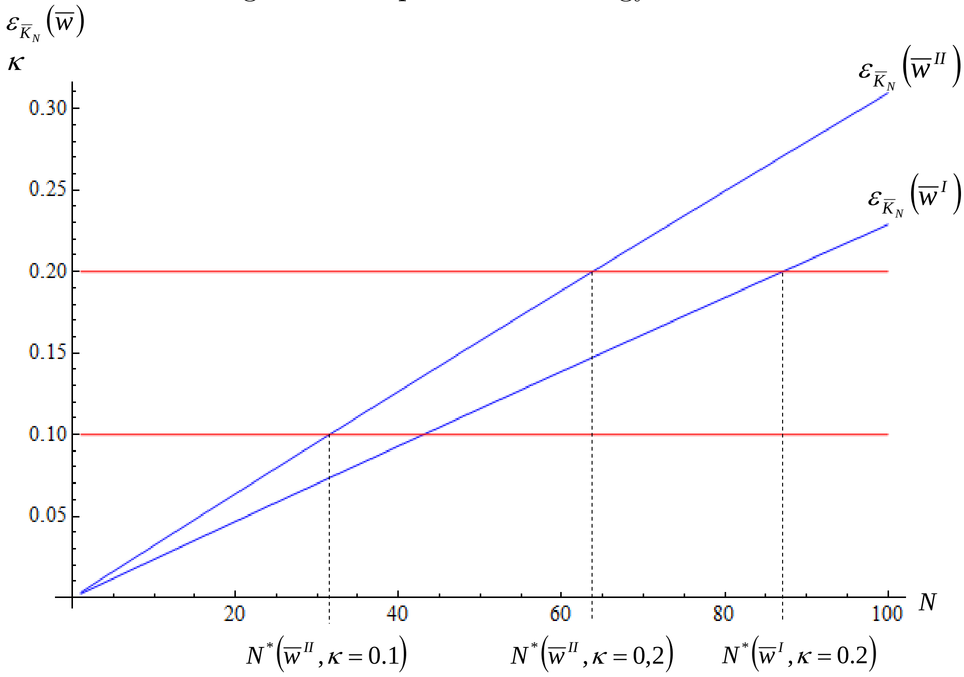
An intuition for the optimal technology choice in (1.9) is given in *Figure 1.1* by simulating

[16] Note that $e^{\kappa\mu} > \bar{w}$ can be easily ensured in general equilibrium since μ is chosen arbitrarily. Furthermore, $\bar{w} > e^{\frac{2\kappa}{1-\kappa\sigma}}$ holds in general equilibrium for defined technology choices, i.e. for $N \in (1, \mu]$. See *Proposition 1.5* for autarky and *Lemma 1.6* for open economy.

[17] (1.9) can be rewritten as $\bar{w}^{N\frac{\sigma}{\mu}} - 1 = \frac{N\frac{\sigma}{\mu}\ln\bar{w}}{1-\kappa\sigma}$ which reveals to be more convenient in calculations.

the right hand side of (1.9). For this purpose, $\varepsilon_{\bar{K}_N}$ is computed explicitly for an array of technology levels where I consider two different skill premia, $\bar{w}^I = 1.6$ and $\bar{w}^{II} = 1.9$, and a constant inter-intermediate input elasticity of $\sigma = 1$[18]. The intersection of $\varepsilon_{\bar{K}_N}(\bar{w})$ with

Figure 1.1: Optimal Technology Choice



Optimal technology choices for two different skill premia. The graphs in red depict the κ's while the graphs in blue represent the $\varepsilon_{\bar{K}_N}$'s.

a firm's technology type, κ, marks a firm's optimal technology choice, which is depicted in *Figure 1.1* as $N^*(\bar{w}, \kappa)$[19]. In the following, I first establish the uniqueness of endogenous level of technology in production and analyze in a second step optimal firm behavior.

Lemma 1.1 *Assume $N \leq \mu$. Then, there exists a unique optimal level of technology.*

The proof is given in Appendix 1.7.6. The assumption $N \leq \mu$ holds under the condition of *Lemma 1.2* in the firm-level analysis and is extended to the general equilibrium in *Proposition 1.5*. Given the type of technological gains in production (κ) and the elasticity of substitution between intermediates (σ), the wage gap uniquely determines the level of technology in production.

[18] All simulations within this dissertation are done with Wolfram Mathematica, Version 8.0.

[19] Note that Acemoglu et al. (2007) compute implicit values of $\kappa = 0.135$ and $\kappa = 0.25$ for the United States.

Lemma 1.2 *The optimal level of technology in production, given $\bar{w}$, can be approximated from (1.9) by*

$$N \approx \frac{2\kappa\mu}{(1-\kappa\sigma)\ln\bar{w}}. \tag{1.10}$$

Then, given that $\bar{w} > e^{\frac{2\kappa}{1-\kappa\sigma}}$ a firm chooses optimally $N \in [0,\mu]$. Furthermore, the optimal level of technology (N) is bigger than one which implies $N \in (1,\mu]$.

The proof is given in Appendix 1.7.6. The approximated level of technology in production exhibits qualitatively the properties of the exact, though implicitly given, solution in (1.9). A skill premium above the threshold $e^{\frac{2\kappa}{1-\kappa\sigma}}$ makes technology adoption so costly that a firm would never choose $N > \mu$. The second property stems from the assumption $e^{\kappa\mu} > \bar{w}$ and ensures that firms with a higher technology type choose a higher level of technology in production and are more productive. The following proposition states the two main comparative statics results of the endogenous level of technology in production.

Proposition 1.1 *A larger skill premium decreases the level of technology: $\frac{dN}{d\bar{w}} = -\frac{N}{\bar{w}\ln\bar{w}} < 0$. Furthermore, a higher technology type (κ) increases the level of technology: $\frac{dN}{d\kappa} = \frac{N}{(1-\kappa\sigma)\left(\frac{N}{\mu}\ln\bar{w}-\kappa\right)} > 0$.*

The proof is given in Appendix 1.7.6. Relative costs of higher-j to lower-j intermediate inputs have a crucial impact on a firm's choice of the level of technology: An increase in the latter requires to add more skill intensive intermediates which becomes profitable when the skill premium decreases. In contrast, the elasticity of average unit costs, $\varepsilon_{\bar{K}_N}$, increases in the wage gap (see *Appendix 1.7.4*) such that very skill intensive intermediates have to be dropped when the skill premium increases. Retrenching the most skill intensive intermediates however dampens automatically the technology level. From a technical point of view, the choice of N has to be lowered to bring $\varepsilon_{\bar{K}_N}$ (see *Appendix 1.7.4*) back to the equilibrium level in (1.9). This is illustrated in *Figure 1.1* where the elasticity of average unit cost intersects κ at a lower optimal technology level when $\bar{w}^I$ rises to $\bar{w}^{II}$ which implies that the optimal choice becomes $N^*\left(w^{II}, \kappa = 0.2\right)$ instead of $N^*\left(w^{I}, \kappa = 0.2\right)$.

In my model, endogenous technology choice allows firms to react more decisively to a wage gap increase than without the capability of a technology downgrade. In the case of an exogenously given level of technology in production, merely the relative employment of $x_{j'}$ to x_j, $\frac{x_{j'}}{x_j} = \bar{w}^{(j-j')\frac{1+\sigma}{\mu}}$ where $j' > j$, can be optimally adjusted. In the proof of *Proposition 1.1*, it is shown that $\frac{x_{j'}}{x_j}$ decreases in the wage gap. A rise in the skill premium would involve a mere shift in the quantities of intermediate inputs from more to less high-skilled intensive ones, but would not decrease the number of intermediates (i.e. the level of technology).

An important factor of the optimal technology choice is the scope for technology in production, κ. Higher κ's imply larger gains from technology such that firms producing with a higher κ choose greater levels of technology in production. Furthermore, the elasticity of average unit costs with respect to N is independent of κ. Assume a firm is endowed with $\kappa = 0.2$ instead of $\kappa = 0.1$. In *Figure 1.1*, the (unaltered) graph of $\varepsilon_{\bar{K}_N}$ would intersect $\kappa = 0.2$ at $N^*\left(w^{II}, \kappa = 0.2\right)$ instead of $N^*\left(w^{II}, \kappa = 0.1\right)$ (see *Figure 1.1*), implying a greater optimal technology level. The firm would add more skill intensive intermediate inputs as the greater scope for technology compensates for the costs incurred by more sophisticated technologies.

1.3.2 Optimal High- to Low-skilled Production Labor Demand

Essentially, the production process is based on the employment of high- and low-skilled labor. The adoption of higher levels of technology in production requires the use of relatively more high-skilled labor. In particular, production labor demands[20] for each intermediate input, production labor demands in each firm as well as relative high- to low-skilled production labor demands are derived in *Appendix 1.7.5.* Production labor demands for each intermediate input j are

$$\begin{aligned} H_j &= \beta^{\frac{1}{1-\beta}} A N^{\frac{\beta(\kappa+1)-1}{1-\beta}} \bar{K}_N^{\sigma-\frac{\beta}{1-\beta}} w_L^{-1-\sigma} \bar{w}^{-\frac{j}{\mu}\sigma-1} \frac{j}{\mu}, \\ L_j &= \beta^{\frac{1}{1-\beta}} A N^{\frac{\beta(\kappa+1)-1}{1-\beta}} \bar{K}_N^{\sigma-\frac{\beta}{1-\beta}} w_L^{-1-\sigma} \bar{w}^{-\frac{j}{\mu}\sigma} \left(1 - \frac{j}{\mu}\right). \end{aligned}$$

[20] Production labor demand is the labor used in the production of the final good, after having incurred labor costs of market entry.

Aggregation over production labor demands of all intermediates within the firm results in

$$H = \beta A p^{\frac{-\beta}{1-\beta}} w_H^{-1} \frac{\kappa}{\ln \bar{w}}, \tag{1.11}$$

$$L = \beta A p^{-\frac{\beta}{1-\beta}} w_L^{-1} \frac{\ln \bar{w} - \kappa}{\ln \bar{w}}. \tag{1.12}$$

Aggregated relative production labor demands[21] within the firm read as

$$\frac{H}{L} = \frac{1}{\bar{w}} \frac{\kappa}{\ln \bar{w} - \kappa} \tag{1.13}$$

and depend on the wage gap ($\bar{w}$) and the type of technology (κ). While the endogenous level of technology has no direct effect on relative production labor demands, $\bar{w}$ and κ jointly determine technology and relative factor demands. Consequently, the complementary nature of technology and skills has to be understood as a positive correlation through common determinants.

Proposition 1.2 *Relative production labor demands ($\frac{H}{L}$) are higher for firms with a greater scope for technology in production. Furthermore, an increase in the skill premium lowers relative production labor demands.*

The proof is given in Appendix 1.7.6. A higher technology type implies a more efficient use of technology in production. Naturally, a firm that is endowed with a higher κ chooses a higher level of technology. The adoption of more sophisticated production techniques requires to add more high-skill intensive intermediate inputs. As a consequence, aggregated relative production demand of high-skilled labor is higher for firms of higher technology types.

An increase in the skill premium raises the implied labor cost of the marginal intermediates above their implied productivity gains in technology terms. They are dropped and, as a consequence, the technology level and relative skill demands decrease. Simultaneously, high-skilled labor is substituted for low-skilled labor in the production of each intermediate input, decreasing in addition the aggregated relative skill demand. Furthermore, the

[21] Total relative labor demands within the firm are $\frac{H}{L} = \frac{1}{\bar{w}} \frac{\kappa}{\frac{\ln \bar{w}}{\beta} - \kappa}$. The assumption $\bar{w} > e^{\kappa\beta}$ ensures that the latter relation is positive and implies in addition a positive relation in (1.13).

relative employment of intermediates changes in favor of less high-skilled intensive inputs as $\frac{x_{j'}}{x_j} = \bar{w}^{(j-j')\frac{1+\sigma}{\mu}}$ $(j < j')$ decreases in $\bar{w}$. All three effects decrease aggregated relative production demands of a firm as a reaction to a rise in the skill premium.

1.3.3 Firm-Level Productivities

Productivity is the most important efficiency measure of producing output from inputs. Here, the use of two inputs, L and H, necessitates the consideration of relative prices. More precisely, productivity is defined as real output over real costs,

$$\phi \equiv \frac{Y}{C(Y)} = \frac{N^{\kappa}}{\bar{K}_N} = N^{\kappa} k_N^{-1} (1 - \kappa\sigma)^{-\frac{1}{\sigma}}, \tag{1.14}$$

where the second equation results from using the optimal technology choice (1.5). Remark that $C(Y)$ also represents real production costs, as $C(Y)/P_I = C(Y)$ where P_I is set to unity in general equilibrium. Given the Cobb-Douglas production of intermediate inputs, productivity becomes

$$\phi = \frac{N^{\kappa}}{w_L \bar{w}^{\frac{N}{\mu}}} (1 - \kappa\sigma)^{-\frac{1}{\sigma}} \tag{1.15}$$

and incorporates, different to the optimal level of technology in production, level effects. In particular, it decreases in the low-skilled wage. Since the optimal choice of technology depends on the skill premium and firm characteristics, changes in the latter also affect productivity.

Proposition 1.3 *Productivity (ϕ) is higher for firms with a higher technology type:* $\frac{\partial \phi}{\partial \kappa} = \ln(N)\phi > 0$. *An increase in the skill premium decreases productivity:* $\frac{\partial \phi}{\partial \bar{w}} = -\frac{\kappa\phi}{\bar{w}\ln\bar{w}} < 0$.

The proof is given in Appendix 1.7.6. As firms with a higher technology type use a higher level of technology in the production process, they profit more from the technology component in production (N^{κ}). This increases overall production and results in a higher productivity. Larger wage gaps increase technology adoption costs and lead to lower choices of technology. As a consequence, the technology component in production shrinks and productivity decreases. Since a firm's use of technology increases in its scope for technology in production, the downgrade of production techniques is stronger for greater levels of κ.

Assume there are two types of firms that differ with respect to the scope for technology in production. Consider in particular multinational and domestic firms which anticipates the analysis of the open economy. There, multinational firms are endowed with κ_m, while domestic firms have a scope for technology of κ_d, where I impose $\kappa_m > \kappa_d$. Furthermore, variables of multinationals are denoted by m and those of domestic firms by d. Then, the relative difference in their productivities is calculated as

$$\phi_\Delta \equiv \frac{\phi_m}{\phi_d} = \frac{N_m^{\kappa_m}}{N_d^{\kappa_d}} \bar{w}^{-\frac{N_m - N_d}{\mu}} \left(\frac{1-\kappa_d \sigma}{1-\kappa_m \sigma} \right)^{\frac{1}{\sigma}}. \tag{1.16}$$

Note that ϕ_Δ does not depend on wage levels, but on the skill premium, the technology types, and the elasticity of substitution between intermediate inputs.

Lemma 1.3 *The productivity difference between multinational and domestic firms decreases in the skill premium:* $\frac{\partial \phi_\Delta}{\partial \bar{w}} = -\phi_\Delta \frac{\kappa_m - \kappa_d}{\bar{w} \ln \bar{w}} < 0$.

The proof is given in Appendix 1.7.6. Since $\kappa_m > \kappa_d$, multinational firms employ relatively more high-skilled labor to implement higher technology levels. As a consequence, they downgrade technology stronger following a wage gap increase, which implies that they lose some of their advantage in technology and productivity. Moreover, the extend to which the productivity gap decreases is proportional to the difference in the respective scopes for technology in production. The latter determine in fact the difference in production techniques where relative downgrades of multinational to domestic firms are the greater the more skill-intensive the production process of multinationals is. In other words, a higher technological advantage involves a production structure of multinationals that relies relatively more on the more expensive factor, i.e. high-skilled labor. As a consequence, the rise in the relative renumeration of skilled workers has more severe effects on multinational than on domestic firms.

1.4 Closed Economy Equilibrium

Firms' choices of the level of technology in production and the related quantities of intermediate inputs are embedded in an autarkic Dixit-Stiglitz economy. A representative household has a taste for variety implied by the utility function

$$u_c = \left(\int_0^{M_{c,d}} Y_{c,d,i}^{\beta} di \right)^{\frac{1}{\beta}}, \quad 0 < \beta < 1,$$

and supplies low- and high-skilled labor (L^s, H^s) inelastically. c denotes variables in closed economy. There exists a continuum of final goods $Y_{c,d,i}$, with $i \in [0, M_{c,d}]$, that are supplied by a (symmetric) mass $M_{c,d}$ of domestic firms of technology type κ_d. $\frac{1}{1-\beta} > 1$ is the elasticity of substitution between final goods. The above preferences imply the demand function

$$Y_{c,d,i} = \left(\frac{p_{c,d,i}}{P_I} \right)^{-\frac{1}{1-\beta}} \frac{A_c}{P_{c,I}} \tag{1.17}$$

where $p_{c,d,i}$ is the price of good i, A_c is the aggregate spending level, and $P_{c,I} \equiv \left(\int_0^{M_{c,d}} p_{c,d,i}^{-\frac{\beta}{1-\beta}} di \right)^{-\frac{1-\beta}{\beta}}$ is the price index of final goods. Defining $P_{c,I}$ as the numeraire $(P_{c,I} \equiv 1)$, the implied demand function for each firm, $A_c p_{c,d,i}^{-\frac{1}{1-\beta}}$, in *Section 1.2.2* becomes identical to (1.17). Whenever there is no loss of clarification I abstract from the firm index i. With optimal firm choices in *Section 1.3.1* and market clearing, equilibrium is defined as:

Definition 1.1 *Equilibrium in a closed economy with symmetric firms is given by a set of prices* $\{p_{c,d}, w_{c,H}, w_{c,L}\}$*, quantities* $\{Y_{c,d}, H_{c,d}, L_{c,d}\}$*, and a level of technology* $N_{c,d}$ *such that with free entry of firms consumers choose consumption of each final good optimally, firms choose output, level of technology and labor inputs optimally, and labor and product markets clear.*

Note that intermediate inputs do not show up directly. They are produced within each firm with high- and low-skilled labor and are aggregated to firm-specific high- and low-skilled labor production demands.

1.4.1 Wages in Closed Economy

There is free entry, but firms have to incur f_d units of low-skilled labor to set up production. Adding this to the production low-skilled labor demand results in a firm's total low-skilled labor demand $(L_{c,d} + f_d)$. The following free entry condition

$$p_{c,d}Y_{c,d} - C(Y_{c,d}) - w_{c,L}f_d = 0 \iff (1-\beta)p_{c,d}Y_{c,d} = w_{c,L}f_d \tag{1.18}$$

fixes the wage level given a firm's revenue. The latter is derived by multiplying the optimal price (1.8) by the optimal output (1.7). Using subsequently the optimal technology choice (1.9) as well as minimal unit costs, $k_j = w_L \bar{w}^{\frac{j}{\mu}}$, results in the following revenue function

$$p_{c,d}Y_{c,d} = \beta^{\frac{\beta}{1-\beta}} A_c N_{c,d}^{\frac{\kappa_d \beta}{1-\beta}} w_{c,L}^{\frac{\beta}{\beta-1}} \bar{w}_c^{\frac{N_{c,d}\beta}{\mu(\beta-1)}} (1-\kappa_d\sigma)^{\frac{\beta}{\sigma(\beta-1)}}. \tag{1.19}$$

Plugging this expression into the free entry condition (1.18) and using total labor income $(w_{c,L}L^s + w_{c,H}H^s = A_c)$ shows that the low-skilled wage

$$w_{c,L} = \beta N_{c,d}^{\kappa_d} \bar{w}_c^{-\frac{N_{c,d}}{\mu}} (1-\kappa_d\sigma)^{-\frac{1}{\sigma}} \left(\frac{(1-\beta)(L^s + \bar{w}_c H^s)}{f_d} \right)^{\frac{1-\beta}{\beta}} \tag{1.20}$$

is a function of labor endowments, parameters, and the skill premium. The wage gap is computed from setting relative labor supply equal to total relative labor demand, $\frac{H^s}{L^s} = \frac{M_{c,d}H_{c,d}}{M_{c,d}(L_{c,d}+f_d)}$. Using (1.11) and (1.12), this implies

$$\bar{w}_c \frac{H^s}{L^s} = \frac{\kappa_d}{\frac{\ln \bar{w}_c}{\beta} - \kappa_d}. \tag{1.21}$$

The above equation implicitly and uniquely determines the skill premium. It depends on the relative scarcity of high-skilled labor $\left(\frac{H^s}{L^s}\right)$, the elasticity between final goods (β), and the firms' scope for technology in production (κ_d).

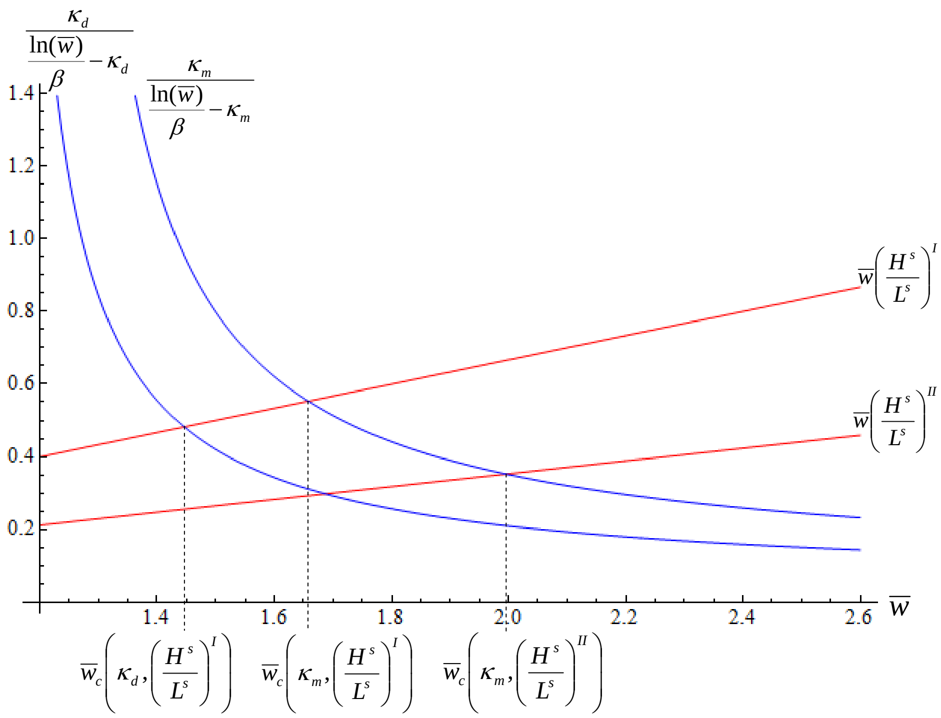
Lemma 1.4 *There exists a unique skill premium. Furthermore, $\bar{w}_c > e^{\kappa_d \beta}$.*

The proof is given in Appendix 1.7.7. The proof builds on the properties of the left and right hand side of (1.21). The existence of an unique skill premium implies that there exists an unique choice of the level of technology in equilibrium, since the wage gap is the only endogenous variable in the equation of the optimal technology choice (1.9).

Proposition 1.4 *The wage gap is lower for higher relative skill endowments ($\frac{H^S}{L^S}$), larger for higher technology types (κ_d), and increases in the elasticity of market demand (β).*

The proof is given in Appendix 1.7.7. A country's high- and low-skill labor endowments are supplied to firms that use technology-complementary production processes. The skill premium represents a measure of the relative scarcity of skills. Holding κ and β constant, the wage gap increases when the relative supply of high- to low-skilled labor decreases. This is illustrated in *Figure 1.2* where the left and right hand side of (1.21) are simulated

Figure 1.2: Skill Premia in Closed Economy



Skill premia in closed economy for different skill endowments and technology types. The graphs in red depict the left hand side of (1.21) while the graphs in blue depict the right hand side of (1.21).

for an array of skill premia. In particular, a fall in the share of skilled workers from 25% to 15%, i.e. a relative skill supply decrease from $\left(\frac{H^s}{L^s}\right)^I$ to $\left(\frac{H^s}{L^s}\right)^{II}$, implies a rise in the skill premium from $\bar{w}_c\left(\kappa_m, \left(\frac{H^s}{L^s}\right)^I\right)$ to $\bar{w}_c\left(\kappa_m, \left(\frac{H^s}{L^s}\right)^{II}\right)$[22]. Firms with a technologically

[22]Note that this section analyzes autarky. κ_m and κ_d are used to depict a closed economy with a high and low technology type, respectively. In open economy analysis, I refer to these cases.

more efficient production function (i.e. a higher κ) choose a higher level of technology and employ more skill intensive intermediate inputs. This is best illustrated by comparing two economies with equal skill endowments, but with firms of different technology types. One is populated by domestic firms such that all firms are endowed with $\kappa_d = 0.16$ while the other consists of multinationals with $\kappa_m = 0.24$. As a consequence, the skill premium in an economy populated exclusively by domestic firms, $\bar{w}_c\left(\kappa_d, \left(\frac{H^s}{L^s}\right)^I\right)$, is well below the wage gap of an economy populated exclusively by multinational firms, $\bar{w}_c\left(\kappa_m, \left(\frac{H^s}{L^s}\right)^I\right)$ (see *Figure 1.2*). As technology is skill-complementary, multinationals demand relatively more high-skilled labor what is settled in equilibrium by a higher wage gap.

Furthermore, higher technology types imply a greater productivity, changing the free entry condition (1.18). For a detailed analysis of how parameters effect free entry in general and equilibrium firm numbers in particular, (1.18) is plugged into the equality of household income and total expenditures ($w_{c,L}L^s + w_{c,H}H^s = M_{c,d}p_{c,d}Y_{c,d}$). This results in the number of firms

$$M_{c,d} = \frac{1-\beta}{f_d}(L^s + \bar{w}_c H^s), \tag{1.22}$$

which clearly increases in the skill premium. Since a larger technology type rises the wage gap, a greater scope for technology in production leads to an increase in the number of firms. Intuitively, an increase in the efficiency of technology in production implies higher expected profits. More firms enter the market while simultaneously the relative renumeration of high-skilled workers increases.

Whereas a greater market elasticity has no effect on relative production labor demands, it increases total relative labor demands and, consequently, the skill premium. The latter, indirect effect, rises the number of firms while the direct effect of β in (1.22) decreases the equilibrium number of firms. However, the total impact on the number of firms is negative[23] as a higher market elasticity increases competition among firms, reduces mark-ups and decrease firms' profits.

[23] $\partial M_{c,d}/\partial\beta = 1/f_d[-L^s - \bar{w}_c H^s(1-\beta(1-\beta)\frac{\ln \bar{w}_c}{\bar{w}_c - \kappa_d\beta + 1})] < 0$ as $\beta(1-\beta)\ln \bar{w}_c + \kappa_d\beta < \bar{w}_c + 1$.

1.4.2 Technology Levels in Closed Economy

The relative endowment of high-skilled labor determines (given κ_d, β) the skill premium that, in turn, is crucial for the decision on the optimal technology level. Very low skill premia that arise from an abundant supply of high-skilled labor may induce firms to choose levels of technology that are not defined (i.e. $N_{c,d} > \mu$). The explicit approximation of the implicitly given level of technology (1.10) leads to the determination of a threshold level of relative skill supply which ensures optimal technology choices within $N_{c,d} \in (1, \mu]$.

Proposition 1.5 *There exists an approximated threshold*

$$\frac{H^s}{L^s} \leq \underbrace{\exp\left(\frac{-2\kappa_d}{1-\kappa_d\sigma}\right)}_{<1} \underbrace{\frac{1-\kappa_d\sigma}{\frac{2}{\beta}-1+\kappa_d\sigma}}_{<1}. \tag{1.23}$$

such that firms optimally choose $N_{c,d} \in [0, \mu]$. Furthermore, $N_{c,d} > 1$ and $N_{c,d} \in (1, \mu]$.

The proof is given in Appendix 1.7.7. The optimal level of technology in production, given the skill premium, can be approximated from (1.9) by (1.10). Then, given the wage gap from equation (1.21), an approximated threshold to the relative supply of skills is derived that restrains firms' choices to the admitted interval. As a consequence, a relative skill endowment smaller than or equal to the threshold ensures an optimal choice of $N_{c,d}$ within $[0, \mu]$. Clearly, the scarcer high-skilled labor is the larger may be the right hand side of (1.23) such that the resulting skill premium still delivers a well defined level of technology.

1.5 Open Economy Equilibrium

Closed economies mirror a very rare case among world's economies. Most countries are, to different extends, open to the entry of multinational firms. Drawing on their international expertise, their use of technology in production is more efficient than that of domestic firms, i.e. $\kappa_m > \kappa_d$[24]. However, MNEs are less familiar with local conditions and may

[24]Since firm-level productivity increases in κ, this assumption implies the empirical observation that MNEs are more productive than domestic firms. See e.g. Doms and Jensen (1998), Dimelis and Louri

have to overcome more bureaucratic and other hurdles to get production units installed and running. This is summarized in higher market entry costs of MNEs[25], $f_m > f_d$, which have to be payed in units of low-skilled labor.

Consider a closed economy that decides to open its market to FDI of multinational firms. A MNE will enter the economy when expected returns from the foreign investment, $\pi_{c,m}(\bar{w}_c) = p_{c,m}(\bar{w}_c)Y_{c,m}(\bar{w}_c) - w_{c,L}f_m \geq 0$, are positive. Note that wages in the decision problem are autarkic wages since at this stage no MNE has entered yet. In addition, the market entry decision of domestic firms is considered by relating their free entry condition (1.18) to $\pi_{c,m}(\bar{w}_c) \geq 0$. This implies that $\phi_\Delta^{\frac{\beta}{1-\beta}}(\bar{w}_c) \geq \frac{f_m}{f_d}$: Market entry of multinationals becomes profitable when the (β weighted) productivity advantage of multinational firms at least equals their fixed costs disadvantage. As a consequence, lowering the relative fixed costs of foreign investments may involve, in my model, the transition from autarky to open economy.

Note that pre-optimization production capabilities of multinational and domestic firms differ only with respect to the technology type. Their optimal choices imply that multinationals produce with a higher level of technology than domestic firms and employ relatively more high-skilled labor in production. The consequence of labor demand differences is that the entry of MNEs will increase the skill premium and will lower in this way the productivity advantage (see *Lemma 1.3*) up to the point where the (β weighted) productivity head start equals relative fixed costs, $\phi_\Delta^{\frac{\beta}{1-\beta}}(\bar{w}_o) = \frac{f_m}{f_d}$. Here, the wage gap in open economy replaces the autarkic skill premium, where o denotes open economy variables[26].

Multinational and domestic firms' choices of the level of technology and the related quantities of intermediate inputs are embedded in a Dixit-Stiglitz economy. A representative household has a taste for variety implied by the utility function

$$u_o = \left(\int_0^{M_{o,d}} Y_{o,d,i}^{\beta} di + \int_0^{M_{o,m}} Y_{o,m,h}^{\beta} dh \right)^{\frac{1}{\beta}},$$

(2002), Proença et al. (2002), Torlak (2004).

[25] See e.g. Aghion et al. (2009) for the impact of different levels of foreign firms' entry costs.

[26] Note further that while the functional form of $N_{k,d}$ ($k \in \{c, o\}$) in (1.9) does not change from autarky to open economy, the implicit wage gaps ($\bar{w}_c$ from (1.21) and $\bar{w}_o$ from (1.29)) that determine technology choices given parameters differ substantially.

and supplies low- and high-skilled labor (L^s, H^s) inelastically. Note that u_o implies that the household does not discriminate between final goods produced by MNEs or domestic firms[27]. Final goods $Y_{o,d,i}$ with $i \in [0, M_{o,d}]$ are supplied by a mass $M_{o,d}$ of domestic firms while a mass $M_{o,m}$ of MNEs supplies final goods $Y_{o,m,h}$, with $h \in [0, M_{o,m}]$. The above preferences imply the demand functions of the household,

$$Y_{o,d,i} = \left(\frac{p_{o,d,i}}{P_I}\right)^{-\frac{1}{1-\beta}} \frac{A_o}{P_{o,I}}, \tag{1.24}$$

$$Y_{o,m,h} = \left(\frac{p_{o,m,h}}{P_I}\right)^{-\frac{1}{1-\beta}} \frac{A_o}{P_{o,I}}, \tag{1.25}$$

where $p_{o,d,i}$ $(p_{o,m,h})$ is the price of good i (h), A_o is the aggregate spending level in open economy, and $P_{o,I} \equiv \left(\int_0^{M_{o,d}} p_{o,d,i}^{-\frac{\beta}{1-\beta}} di + \int_0^{M_{o,m}} p_{o,m,h}^{-\frac{\beta}{1-\beta}} dh\right)^{-\frac{1-\beta}{\beta}}$ is the price index of final goods. Defining $P_{o,I}$ as the numeraire $(P_{o,I} \equiv 1)$, the implied demand function for each i (h) firm, $A_o p_{o,d,i}^{-\frac{1}{1-\beta}}$ $\left(A_o p_{o,m,h}^{-\frac{1}{1-\beta}}\right)$, in *Section 1.2.2* becomes identical to (1.24) $\Big((1.25)\Big)$. Whenever there is no loss of clarification I will abstract from firm indices i and h in the following . With optimal firm choices in *Section 1.3.1* and market clearing, equilibrium is defined as:

Definition 1.2 *Equilibrium in an open economy with symmetry among domestic and symmetry among multinational firms is given by a set of prices* $\{p_{o,d}, p_{o,m}, w_{o,H}, w_{o,L}\}$, *quantities* $\{Y_{o,d}, Y_{o,m}, H_{o,d}, H_{o,m}, L_{o,d}, L_{o,m}\}$, *and levels of technology* $\{N_{o,d}, N_{o,m}\}$ *such that with free entry of domestic and multinational firms consumers choose consumption of each final good optimally, firms choose outputs, levels of technology, and labor inputs optimally, while labor and product markets clear.*

1.5.1 Wages and Technologies with a Fixed Number of MNEs

First, I assume that a fixed number of multinational firms $(M_{o,m})$ enters the economy while domestic firms' entry is endogenous. This assumption will be relaxed subsequently by endogenizing the entry of MNEs. Nevertheless, the main result of this analysis (stated in

[27]This is implied by the CES. However, $Y_{o,d,i}$ will be smaller than $Y_{o,m,h}$ since MNEs have higher productivities, involving lower prices. In particular, abstracting from indices, $p = \frac{1}{\beta\phi}$ from (1.8.) and (1.14)

Proposition 1.6) holds irrespective of exogenous or endogenous entry as long as parameters and endowments imply the endogenous entry of both type of firms.

Since the number of multinational firms is fixed, the skill premium is computed analog to the closed economy case by equating relative labor supply with relative labor demand,

$$\frac{H^s}{L^s} = \frac{M_{o,d}H_{o,d} + M_{o,m}H_{o,m}}{M_{o,d}(L_{o,d} + f_d) + M_{o,m}(L_{o,m} + f_m)}. \tag{1.26}$$

Domestic firms may freely enter. However, in the case of an enormous technology advantage of multinationals or a great given number of MNEs in the economy, they may also decide to stay out of the market. Using firm-level revenues (1.19), ϕ_Δ, and total labor renumeration ($A_o = w_{o,L}L^s + w_{o,H}H^s$) in product market clearing ($A_o = M_{o,d}p_{o,d}Y_{o,d} + M_{o,m}p_{o,m}Y_{o,m}$) results in the number of domestic firms,

$$M_{o,d} = \frac{(1-\beta)}{f_d}(L^s + \bar{w}_o H^s) - M_{o,m}\phi_\Delta^{\frac{\beta}{1-\beta}}. \tag{1.27}$$

This calls in mind the number of domestic firms in closed economy (1.22), reduced by the given number of MNEs. Moreover, the latter is weighted by multinational firms' productivity advantage which is, in turn, weighted by the market elasticity (β). Applying firm-level high- and low-skilled labor demands ((1.11), (1.12)), together with the number of domestic firms (1.27), to the relation of labor supply and demand (1.26) results in

$$\bar{w}_o\frac{H^s}{L^s} = \frac{(L^s + \bar{w}_o H^s)\,\kappa_d\frac{1-\beta}{f_d} + (\kappa_m - \kappa_d)\phi_\Delta^{\frac{\beta}{1-\beta}}M_{o,m}}{\left(\frac{\ln(\bar{w}_o)}{\beta} - \kappa_d\right)(L^s + \bar{w}_o H^s)\frac{1-\beta}{f_d} - \left((\kappa_m - \kappa_d)\,\phi_\Delta^{\frac{\beta}{1-\beta}} + \left(\phi_\Delta^{\frac{\beta}{1-\beta}} - \frac{f_m}{f_d}\right)\frac{1-\beta}{\beta}\ln(\bar{w}_o)\right)M_{o,m}}. \tag{1.28}$$

The closed economy skill premium (1.21) can be easily obtained by setting $M_{o,m} = 0$. When domestic firms are crowded out completely by multinationals, i.e. if (1.27) implies $M_{o,d} = 0$, a skill premium equation similar to the autarkic case emerges. However, the symmetric technology type will be κ_m instead of κ_d. When multinationals have completely replaced domestic firms the skill premium is higher than in autarky, since *Proposition 1.4* implies a higher wage gap for greater scopes for technology in production.

Proposition 1.6 *Assume an open economy populated by positive numbers of multinational and domestic firms such that both types of firms have an incentive to enter. Then, the wage gap in open economy is higher than in closed economy. Moreover, domestic firms' levels of technology in production and their productivities are lower than in autarky.*

The proof is given in Appendix 1.7.8. The intuition is straightforward. Multinational and domestic firms expect positive returns from market entry. However, the entry of MNEs is sufficient for an increase in the wage gap. In particular, multinationals demand relatively more high-skilled labor than domestic firms which implies a rise in aggregated relative skilled labor demand. As a consequence, the skill premium increases in equilibrium since high- and low-skilled labor markets have to be cleared simultaneously. The impact on domestic firms works via the labor market channel: The rise in the skill premium decreases the technology choice of domestic firms since the employment of technology-complementary high-skilled labor becomes relatively more expensive.

1.5.2 Wages and Technologies with Free Entry

The restrictive assumption of a fixed number of MNEs is relaxed in the following. In particular, zero profit conditions of multinational and domestic firms endogenize firm numbers. Moreover, my focus is on the comparison of different equilibria while I abstract from transitional dynamics. Remark that free entry does not change the main result of my paper given in *Proposition 1.6*, as the latter is derived from equation (1.28) which still holds for endogenous firm numbers, $M_{o,m}$ and $M_{o,d}$.

However, in contrast to the equilibrium with a given number of MNEs (or to the closed economy equilibrium with free entry), the skill premium is not determined by relative total labor demands and supply. Rather, it is derived from free entry conditions of multinational ($p_{o,m}Y_{o,m} = \frac{w_{o,L}f_m}{1-\beta}$) and domestic firms ($p_{o,d}Y_{o,d} = \frac{w_{o,L}f_d}{1-\beta}$) in combination with respective revenues of firms (apply (1.19) to m- and d-firms):

$$\phi_{\Delta}^{\frac{\beta}{1-\beta}}(\bar{w}_o) = \frac{f_m}{f_d}. \tag{1.29}$$

As described in the beginning of *Section 1.5*, the entry of multinationals drives up the skill premium and, consequently, decreases the productivity advantage up to the point where foreign firms are indifferent with respect to entry. In equilibrium, the wage gap becomes a function of technology types (κ_m, κ_d), market elasticity (β), inter-input elasticity (σ), and relative fixed cost $\left(\frac{f_m}{f_d}\right)$ since $\phi_\Delta \equiv \frac{\phi_m}{\phi_d} = \frac{N_m^{\kappa_m}}{N_d^{\kappa_d}} \bar{w}^{-\frac{N_m - N_d}{\mu}} \left(\frac{1-\kappa_d\sigma}{1-\kappa_m\sigma}\right)^{\frac{1}{\sigma}}$. Moreover, these parameters also determine whether both types of firms enter the market which is analyzed in *Section 1.5.3.*

Note that an equilibrium in open economy where both types of firms coexist involves that relative skill supplies have no implications for the skill premium. Rather, foreign and domestic firms differ in their output reactions towards an increase in skill supply. More precisely, firms' output elasticities are[28]

$$\frac{\partial Y_{o,m}}{\partial H^s}\frac{H^s}{Y_{o,m}} = \frac{\partial Y_{o,d}}{\partial H^s}\frac{H^s}{Y_{o,d}}. \tag{1.30}$$

An increase in the high-skill endowment (H^s) raises firm-level outputs such that the elasticities of output with respect to H^s equalize. However, multinationals produce more than domestic firms, i.e. ($Y_{o,m} > Y_{o,d}$) as they are more productive ($\phi_\Delta > 1$). A direct implication is that they profit relatively more from an increase in H^s than domestic firms $\left(\frac{\partial Y_{o,m}}{\partial H^s} > \frac{\partial Y_{o,d}}{\partial H^s}\right)$ since their higher degree of gains from technology in production involves that they use H^s more efficiently[29].

Proposition 1.7 *There exists a unique skill premium if $\phi_\Delta(\chi)^{\frac{\beta}{1-\beta}} \geq \frac{f_m}{f_d}$. The skill premium increases in the technology type of multinationals (κ_m) and decreases in the technology type of domestic firms (κ_d) as well as in relative fixed costs ($\frac{f_m}{f_d}$).*

The proof is given in Appendix 1.7.8 [30]. The open economy skill premium, provided the coexistence of MNEs and domestic firms, is larger than the autarkic wage gap but smaller

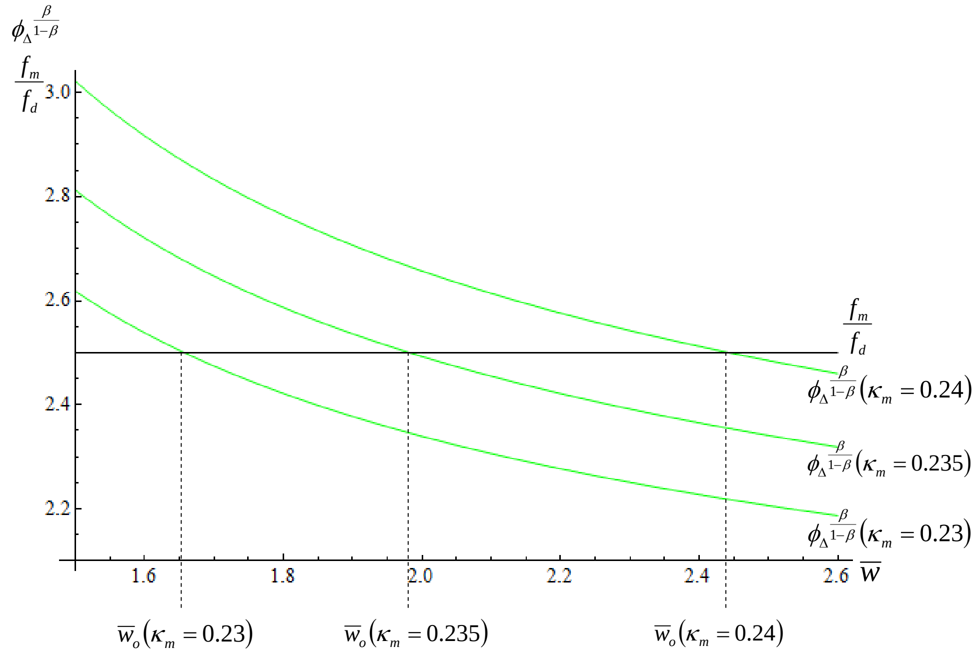
[28] Since in an open economy with MNEs and domestic firms $d\bar{w}/dH^s = 0$, it holds, using (1.7), that $\partial Y_{o,i}/\partial H^s = (Y_{o,i}/A)(\partial A/\partial H^s)$ for $i \in \{m, d\}$.

[29] This calls in mind the well known Rybczynski Theorem: Relative factor prices (here $\bar{w}$) are stable but firms that use the factor that increases more intensively (multinationals) produce proportionally more, while the others (domestic firms) produce proportionally less. Furthermore, $M_{o,d}$ (see (1.32)) increases in L^s and decreases in H^s while for $M_{o,m}$ (see (1.31)) the opposite holds. Intuitively, firms that use a factor more intensively increase in numbers if the respective endowment grows and decrease in numbers if it shrinks.

[30] Note that $\chi \equiv \exp\left[\frac{\beta}{2}\left(\left(\frac{1}{\beta} - \kappa_d\right)^2 + \frac{4\kappa_d}{\beta}\left(1 + \frac{L^s}{H^s}\right)\right)^{\frac{1}{2}} - \frac{1}{2} + \frac{\kappa_d\beta}{2}\right]$.

than the skill premium implied by the exclusive entry of MNEs. An approximation of the skill premium in closed economy provides thus a lower bound to all skill premia (χ) which is given by β, κ_d, H^s, and L^s. Since $\phi_\Delta(\bar{w})^{\frac{\beta}{1-\beta}}$ is strictly decreasing in $\bar{w}$, a sufficient condition that $\phi_\Delta(\bar{w})^{\frac{\beta}{1-\beta}}$ intersects $\frac{f_m}{f_d}$ exactly once is that $\phi_\Delta(\chi)^{\frac{\beta}{1-\beta}} \geq \frac{f_m}{f_d}$ holds. Moreover, the existence of an unique skill premium makes sure that the technology choices of firms exist and are unique.

Figure 1.3: Skill Premia in Open Economy



Skill premia in open economy for different degrees of gains from technology in production of MNEs. The black line depicts relative market entry costs and the green graphs denote (weighted) productivity gaps for different κ_m's.

Figure 1.3 illustrates the existence of a unique skill premium which is located at the intersection of the adjusted productivity gap $\left(\phi_\Delta(\bar{w})^{\frac{\beta}{1-\beta}}\right)$ and relative fixed costs $\left(\frac{f_m}{f_d}\right)$[31]. Whereas the graph of the former is convex and downward sloping, the graph of the latter is a parallel to the abscissa. Differences in the technology type of multinationals translate into different adjusted productivity gaps which intersect relative fixed costs at the

[31]If not otherwise stated simulations in open economy are carried out with $\kappa_m = 0.24$, $\kappa_d = 0.16$, $\sigma = 1$, $\mu = 100$, $H^s = 15$, $L^s = 85$, $f_d = 1$, $f_m = 2.5$, and $\beta = 0.75$. Note that the value of β is within the standard range of estimates, as e.g. in Broda et al. (2006). Shares of high- and low-skilled labor endowments of 15%, respectively 85% apply to a range of countries.

equilibrium value of the skill premium. A higher κ_m widens the spread in chosen technology levels between MNEs and domestic firms such that the graph of $\phi_{\Delta}^{\frac{\beta}{1-\beta}}$ is shifted upwards. Given a constant $\frac{f_m}{f_d}$, the equilibrium level of the wage gap is shifted to the right. Intuitively, a higher technology type of multinationals involves a greater advantage in technology and productivity of MNEs. Their shares in the production of output and the demand of labor increase, driving up the aggregated relative demand of high-skilled labor and, consequently, the skill premium. In *Figure 1.3*, this is illustrated by the upward shift of the (weighted) productivity gap which results in an increase of the equilibrium wage gap from e.g. $\bar{w}_o(\kappa_m = 0.23)$ to $\bar{w}_o(\kappa_m = 0.24)$. While aggregated relative skill demands have no direct impact on the wage gap, κ_m and κ_d jointly determine aggregated relative skill demands and the wage gap. Consequently, the complementary nature of aggregated relative demands of high-skilled labor and the skill premium has to be understood as a positive correlation through common determinants. A similar reasoning applies to an increase in κ_d's which narrows the spread of technology types. Domestic firms increase their shares in the demand of labor and the production of output which diminises aggregated relative skill demand, and drives down the wage gap. Moreover, higher relative fixed costs (i.e. an upward shift of $\frac{f_m}{f_d}$ in *Figure 1.3*) make market entry less attractive for multinationals. As a consequence, the share of domestic firms in the market increases. Since the latter demand relatively less high-skilled labor, the skill premium decreases.

1.5.3 Endogenous Numbers of MNEs and Domestic Firms

Up to this point, I implicitly assume that there exist parameters such that either multinational and domestic firms enter simultaneously or that multinationals, respectively domestic firms, enter exclusively. For a more thorough analysis of firm entry decisions, numbers of multinational and domestic firms are computed. Moreover, conditions for coexistence or exclusive entry are derived.

Solving the skill premium equation given the number of MNEs (1.28) for $M_{o,m}$ and plugging the result in the respective number of domestic firms (1.27) (while using also the equation of the equilibrium wage gap (1.29)) provides the number of multinational firms,

$$M_{o,m} = \frac{(1-\beta)(\bar{w}_o H^s(\frac{\ln(\bar{w}_o)}{\beta} - \kappa_d) - \kappa_d L^s)}{f_m(\kappa_m - \kappa_d)}. \tag{1.31}$$

Moreover, the above expression is applied to the number of domestic firms given MNEs (1.27) and $\phi_\Delta^{\frac{\beta}{1-\beta}}$ is substituted by $\frac{f_m}{f_d}$ (1.29), which results in the equilibrium number of domestic firms

$$M_{o,d} = \frac{(1-\beta)(\kappa_m L^s - \bar{w}_o H^s(\frac{\ln(\bar{w}_o)}{\beta} - \kappa_m))}{f_d(\kappa_m - \kappa_d)}. \tag{1.32}$$

Lemma 1.5 *Assume that multinational and domestic firms enter the market. Then, the number of domestic firms increases in κ_d and $\frac{f_m}{f_d}$; It decreases in κ_m and the skill premium. The number of multinational firms increases in κ_m and the skill premium; It decreases in κ_d and $\frac{f_m}{f_d}$.*

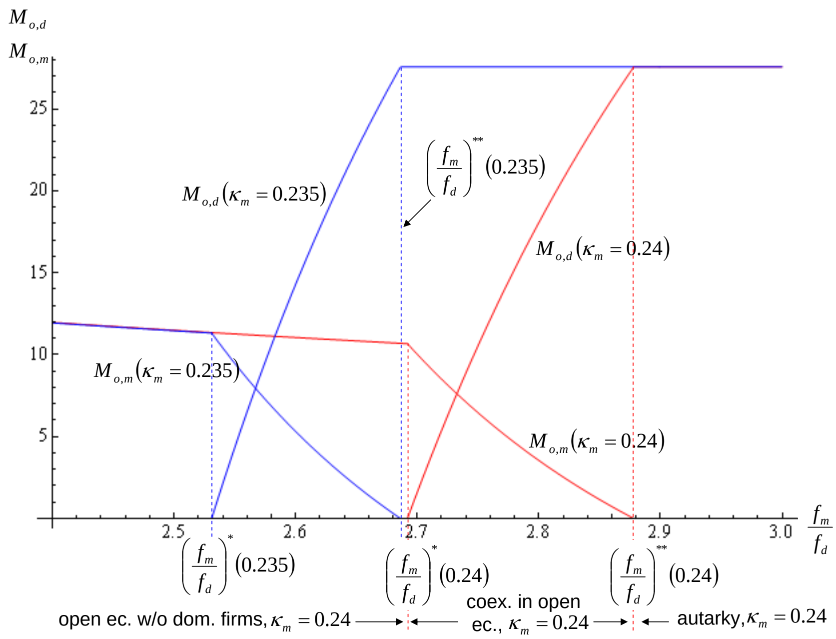
The proof is given in Appendix 1.7.8. A domestic firm gains from a higher technology type in terms of technology and productivity, inducing more domestic firms to enter. Larger relative fixed costs imply higher market entry costs for multinationals relative to domestic firms. Less multinationals enter the economy, implying a decrease in the skill premium. This induces domestic firms to choose higher levels of technology in production, increasing their productivity. As a consequence, expected profits from market entry rise and more domestic firms enter the economy. Inversely, a higher κ_m increases the technology choice and, thus, the productivity advantage of multinationals. The wage gap is driven up and less domestic firms enter the market. The direct effect of the wage gap on domestic firm numbers is also negative, but its interpretation has to be more cautious due to its endogenous nature. Most changes in parameters effect firm numbers directly and, in addition, indirectly via an impact on the skill premium.

Similarly, the number of MNEs increases when they are endowed with a higher κ_m, implying a greater technological and productivity advantage. Their number however decreases if their advantage shrinks, e.g. if κ_d rises. Moreover, higher relative market entry costs make FDI in the domestic market less attractive for multinational firms. The following proposition determines conditions under which multinationals *and/or* domestic firms enter the market.

Proposition 1.8 *Holding all other parameters constant,* $\forall \frac{f_m}{f_d} \in \left(\left(\frac{f_m}{f_d}\right)^*, \left(\frac{f_m}{f_d}\right)^{**}\right)$ *where* $\left(\frac{f_m}{f_d}\right)^* < \left(\frac{f_m}{f_d}\right)^{**}$*, domestic firms as well as MNEs enter the market.* $\forall \frac{f_m}{f_d} \leq \left(\frac{f_m}{f_d}\right)^*$*, exclusively multinationals and* $\forall \frac{f_m}{f_d} \geq \left(\frac{f_m}{f_d}\right)^{**}$*, exclusively domestic firms enter. Moreover,* $\left(\frac{f_m}{f_d}\right)^*$ *is increasing in* κ_m *and* $\left(\frac{f_m}{f_d}\right)^{**}$ *is decreasing in* κ_d*.*

The proof is given in Appendix 1.7.8. The proposition describes the different ranges of fixed costs that imply *either* the exclusive entry of multinational or domestic firms *or* the simultaneous market entry of both. This is illustrated in *Figure 1.4* where three different types of economies are distinguished where the relation of parameters determines the observed type. Note that since there exists a unique skill premium in each type of economy, $M_{o,d}$, $M_{o,m}$, $N_{o,d}$, and $N_{o,m}$ are characterized uniquely within each economy. First, consider the case of $\frac{f_m}{f_d} \leq \left(\frac{f_m}{f_d}\right)^*$. Here, exclusively multinational firms enter since

Figure 1.4: Numbers of Multinational and Domestic Firms



Numbers of multinational and domestic firms in the economy. Red depicts numbers of MNEs and domestic firms if $\kappa_m = 0.24$ while the graphs in blue represent numbers of MNEs and domestic firms if $\kappa_m = 0.235$. $\left(\frac{f_m}{f_d}\right)^*(0.24)$ and $\left(\frac{f_m}{f_d}\right)^{**}(0.24)$ are the thresholds between different types of economies for $\kappa_m = 0.24$ and $\left(\frac{f_m}{f_d}\right)^*(0.235)$ and $\left(\frac{f_m}{f_d}\right)^{**}(0.235)$ are the thresholds between different types of economies for $\kappa_m = 0.235$.

their technological advantage far outweighs their disadvantage in relative market entry costs. Second, if $\frac{f_m}{f_d} \in \left(\left(\frac{f_m}{f_d}\right)^*, \left(\frac{f_m}{f_d}\right)^{**}\right)$, MNEs and domestic firms enter since the advantage in technology of the former is, to some extend, balanced by their higher relative fixed costs. However, the greater the disadvantage in relative market entry costs the less MNEs and the more domestic firms enter. Of course, numbers of domestic firms decline as soon as multinationals gain some market share. This can be seen in *Figure 1.4* where $M_{o,d}(\kappa_m = 0.24)$ clearly decreases if, starting from $\left(\frac{f_m}{f_d}\right)^{**}(0.24)$, relative market entry costs are lowered. Third, $\forall \frac{f_m}{f_d} \geq \left(\frac{f_m}{f_d}\right)^{*}$ MNEs' fixed cost disadvantage outweighs their technological advantage and the economy is, as in autarky, exclusively populated by domestic firms. Remark that the number of multinational firms in the first case is lower than that of domestic firms in the third since κ_m's positive impact on the skill premium is less strong on the number of MNEs than their burden of higher market entry costs (see firm numbers in an economy populated by one type of firms (1.22)).

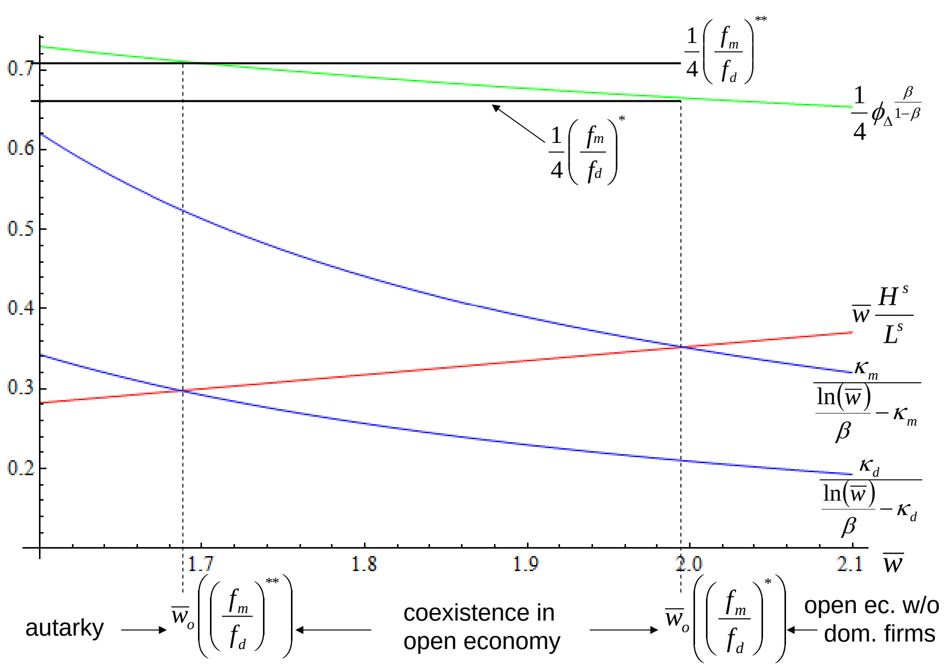
The second property of *Proposition 1.8* states that if κ_m, increases market entry becomes profitable for multinationals for higher values of relative fixed costs. Or, if κ_d rises, the autarkic situation prevails for lower relative market entry costs since the technology disadvantage of domestic firms shrinks. The former case is illustrated in *Figure 1.4* where two different scopes for technology in production of MNEs are considered. The range of relative market entry costs that implies coexistence of MNEs and domestic firms in the market, $\left(\left(\frac{f_m}{f_d}\right)^{*}(0.24), \left(\frac{f_m}{f_d}\right)^{**}(0.24)\right)$, shifts to $\left(\left(\frac{f_m}{f_d}\right)^{*}(0.235), \left(\frac{f_m}{f_d}\right)^{**}(0.235)\right)$ if the technology type of multinational firms is decreased from $\kappa_m = 0.24$ to $\kappa_m = 0.235$. Note that the latter small decrease has a huge impact in this model since even small changes in the difference of the firms' scopes for technology in production, $\kappa_m - \kappa_d$, involve large changes in relative productivities and, thus, the skill premium [32]. A smaller κ_m implies a smaller technology advantage of domestic firms such that domestic firms enter for lower values of relative fixed costs, i.e. $\left(\frac{f_m}{f_d}\right)^{*}(0.24)$ is shifted to $\left(\frac{f_m}{f_d}\right)^{*}(0.235)$. Moreover, $\left(\frac{f_m}{f_d}\right)^{**}$ also decreases since lower κ_m involve that market entry is less profitable for MNEs for higher relative fixed costs.

[32]See *Figure 1.3* for the impact of different κ_m's on the skill premium.

1.5.4 Skill Premia and Domestic Firms' Technology Choices in Closed Versus Open Economy

In *Proposition 1.6*, it is shown that the entry of MNEs decreases the endogenous technology level of domestic firms. Moreover, I provide conditions for market entry of multinationals in the above section. Since domestic firms downgrade their technologies as a reaction to the skill premium increase induced by the entry of multinationals, the specific determination of skill premia in autarky and open economy deserves more attention. *Figure 1.5* illustrates the determination of the skill premium in three distinct cases: au-

Figure 1.5: Skill Premium in Closed Versus Open Economy



Skill premium equations in closed and open economy for different values of relative market entry costs. The green and black graphs depict the left and right hand side of the skill premium equation in the case of coexistence in open economy (1.29). The red graph describes the left hand side of the wage gap equation of an economy populated by a single type of firms (1.21). The blue graphs depict the latter's right hand side, with κ_d in the case of domestic firms and κ_m in the case of multinationals.

tarky, open economy with coexistence of MNEs and domestic firms, and open economy without domestic firms[33]. In each case, the equilibrium value of the wage gap is given by

[33] Note that for reasons of presentation, $\phi_\Delta^{\frac{\beta}{1-\beta}}$, $\left(\frac{f_m}{f_d}\right)^*$, and $\left(\frac{f_m}{f_d}\right)^{**}$ are divided by four. Note further that there exists no continuity of the implicit function of the skill premium when the economy passes

the intersection of the left and right hand side of the respective implicit wage gap equation[34]. Which economy emerges depends in particular on the difference in multinational and domestic firms' scope for technology in production and relative market entry costs. Relative fixed cost above $\left(\frac{f_m}{f_d}\right)^{**}$ preclude the entry of multinationals and imply the wage gap $\bar{w}_o\left(\frac{f_m}{f_d}\right)^{**}$ that equals the closed economy skill premium which is determined by the intersection of $\bar{w}\frac{H^s}{L^s}$ and $\frac{\kappa_d}{\frac{\ln\bar{w}}{\beta}-\kappa_d}$ (see (1.21)). In this case, domestic firms choose autarkic technology levels. However, relative fixed costs below $\left(\frac{f_m}{f_d}\right)^{*}$ involve that multinationals' technological advantage outweighs their fixed costs disadvantage such that domestic firms are completely crowded out. In this case, $\bar{w}_o\left(\frac{f_m}{f_d}\right)^{*}$ represents the skill premium of an economy populated exclusively by multinationals which is given by the intersection of $\bar{w}\frac{H^s}{L^s}$ and $\frac{\kappa_m}{\frac{\ln\bar{w}}{\beta}-\kappa_m}$ (see (1.21) with κ_m instead of κ_d). Here, domestic firms are forced to downgrade technology to an extend where market entry is no longer profitable. Within the range of coexistence, $\left(\left(\frac{f_m}{f_d}\right)^{*},\left(\frac{f_m}{f_d}\right)^{**}\right)$, both types of firms enter and an intermediate wage gap $\bar{w}_o$ emerges where $\bar{w}_o\left(\left(\frac{f_m}{f_d}\right)^{**}\right) < \bar{w}_o < \bar{w}_o\left(\left(\frac{f_m}{f_d}\right)^{*}\right)$. This implies that domestic firms lower their level of technology in production compared to the level in autarky. However, the skill premium increase is affected by the number of multinationals that enter the economy since a downward-sloping (β-weighted) relative productivity curve, $\phi_\Delta^{\frac{\beta}{1-\beta}}(\bar{w})$, intersects higher relative market entry costs at lower wag gaps. Moreover, higher relative fixed costs imply a lower number of MNEs in the market (see *Figure 1.5*) while a greater scope for technology in production of MNEs increases their number. As a consequence, the extent to which domestic firms' optimal technology choices decrease in open economy depends crucially on the relation of multinationals' technological advantage to their fixed costs disadvantage. This implies, e.g., that within the range of coexistence, lower relative market entry costs lead to higher skill premia and, consequently, less sophisticated production techniques of domestic firms.

Furthermore, *Figure 1.5* illustrates how a sufficient condition for defined technology choices (i.e. $N_{o,d}, N_{o,m} \leq \mu$) can be derived from extending the condition in autarky that assures $N_{c,d} \leq \mu$ (*Proposition 1.5*) to the open economy equilibrium.

from closed (1.21) to open economy (1.29). In particular, the wage gap equations do not converge for $M_{o,d} \to 0$ or $M_{o,m} \to 0$. Rather, three cases have to be distinguished and need to be taken into account in the analysis.

[34]For autarky (1.21), for coexistence in open economy (1.29), and for an open economy without domestic firms (1.21) where κ_d is replaced by κ_m.

Lemma 1.6 *$N_{o,d} \leq \mu$ and $N_{o,m} \leq \mu$ hold if*

$$\frac{H^s}{L^s} \leq \exp\left(\frac{-2\kappa_m}{1-\kappa_m\sigma}\right)\frac{1-\kappa_m\sigma}{\frac{2}{\beta}\frac{\kappa_m}{\kappa_d}-1+\kappa_m\sigma}. \tag{1.33}$$

The proof is given in Appendix 1.7.8. From the firm-level analysis of technology choices, two dependencies are known. First, the level of technology increases in the scope for technology in production, κ. Since $\kappa_m > \kappa_d$, it is sufficient to show that $N_{o,m} \leq \mu$. Second, the optimal technology choice decreases in the skill premium. Consequently, $N_{o,m}$ attains its highest level in an economy that implies the lowest $\bar{w}$. As the wage gap decreases in κ, this represents an economy populated by domestic firms with a single (marginal) multinational. Combining the respective wage gap equation with a restriction to the approximated technology choice of the multinational firm delivers the threshold given by (1.33). Remark that the latter is smaller than the threshold in autarky, (1.23), as high-skilled labor has to be more scarce to oppose the multinational's higher scope for technology in production. Moreover, the skill premium in the coexistence equilibrium does not depend on labor endowments. However, as illustrated in *Figure 1.5*, it is limited from above by the wage gap of an economy populated exclusively by multinationals and from below by the skill premium in autarky. Hence, although relative skill endowments have no direct impact on the wage gap in the coexistence equilibrium, they are included in the general condition of defined technology choices in open economy.

1.6 Conclusion

The emergence of technology leading firms that produce and sell on a global scale and the associated increase in FDI flows have far-reaching consequences for host countries' production processes. Moreover, empirical studies provide mixed results on the impact of FDI on domestic firms' choices of production techniques whereas the theoretical literature focuses in particular on knowledge spillovers. In contrast, little research has been conducted to unveil the effects of increased factor market competition on domestic firms' production technologies.

In this chapter, I overcome this shortfall by explicitly focusing on the impact of a toughened factor market competition, provoked by the entry of multinational firms, on the endogenous technology choices of domestic firms. For this purpose, I provide a new firm-level production function that links the endogenous technology decision to the demands of high- and low-skilled labor. Moreover, MNEs are more productive than domestic firms since they have an advantage in the use of technology in production. As technology is skill-complementarity, the entry of multinational firms via FDI increases the demand of skilled labor which induces an increase in the skill premium. In particular, a higher wage gap rises the technology adoption costs of all firms, forcing domestic firms to downgrade their chosen level of technology production. Moreover, the extend to which domestic firms have to downgrade their production techniques depends on the relation of MNEs' advantage in the use of technology to their higher costs of market entry.

This study isolates the labor market channel of the effects of FDI on the choice of production techniques of domestic firms. Nevertheless, competition on output markets, learning, or knowledge spillovers might interact with high- and low-skilled labor demands. In particular, learning or knowledge spillovers could increase domestic firms' scope for technology in production, eventually converging to multinational's scope. Or, MNEs could start learning from domestic firms in terms of market entry costs. Furthermore, regulation of FDI inflows could be altered such that a change in market entry costs for foreign firms induces more or less multinational firms to enter. As a consequence, depending on the precise nature of interactions, the impact on domestic firms' technology choices could be mitigated or enforced which provides a fruitful field of future research.

1.7 Appendix A1

1.7.1 Homogeneous Versus Heterogeneous Intermediate Inputs

Acemoglu et al. (2007) present the production function (1.1) with homogeneous intermediate inputs j and symmetric minimal unit costs ($k_j = k \quad \forall j$). In this case, concavity implies symmetry: $x(j) = x(j')$ for all $j, j' \in [0, N]$. Hence, $Y = N^{\kappa+1}x$ and profits are given by

$$\Pi (N, x) = A^{1-\beta} Y^{\beta} - Nkx - C(N).$$

Here, $C(N)$ is the cost of employing technology N. If all intermediates are equally expensive, $C(N)$ is necessary to obtain a finite choice of N. In my model, $C = 0$ as the cost of technology adoption are fully integrated in the production function of intermediates. Comparing the two models' resulting elasticities of output with respect to N is only feasible if I consider post-maximization elasticity within my model. My model's elasticity is smaller than Acemoglu et al. (2007)'s $(\kappa + 1)$ as mine incorporates conditions for a finite choice of N $(1 - \sigma\kappa > 0)$. Furthermore, with heterogeneous production of intermediate inputs, gains from technology and the elasticity of substitution between different intermediates cannot be separated additively (as it is feasible in the case with homogeneous intermediates) and are intertwined. However, they are still governed by two distinct parameters, κ and σ, where the elasticity between intermediates is driven only by σ.

The first-order maximization conditions with respect to N and x in Acemoglu et al. (2007) imply

$$\beta^{\frac{1}{1-\beta}} A N^{\frac{\beta[\kappa+1]-1}{1-\beta}} \kappa = k^{\frac{\beta}{1-\beta}} C'(N) \quad \text{and} \quad x = \frac{C'(N)}{\kappa k}$$

such that the optimal technology choice as well as its uniqueness depends crucially on the functional form of $C(N)$. In contrast, my model allows for an endogenous level of technology without any additional cost function since I introduce skill-complementarity of technology. The latter implies that cost of technology adoption increase in the level of technology.

1.7.2 Minimal Unit Costs in the Adjusted Cobb-Douglas Case

Consider the production function of intermediate inputs (1.2) and abstract from indices. Minimize

$$w_L L + w_H H \quad s.t. \quad z L^{1-\zeta} H^{\zeta} = \bar{x}, \quad \zeta \in (0,1)$$

where $z = \zeta^{-\zeta}(1-\zeta)^{-(1-\zeta)}$ and $\bar{x}$ is a given intermediate output. The Langrangian $\mathcal{L} = w_L L + w_H H - \lambda\left(zL^{1-\zeta}H^{\zeta} - \bar{x}\right)$ leads to the following first order conditions

$$w_L = \lambda(1-\zeta)z\left(\frac{H}{L}\right)^{\zeta}, \qquad w_H = \lambda\zeta z\left(\frac{H}{L}\right)^{\zeta-1}.$$

Combining the first order conditions leads to the relative factor demand, $H = L\frac{w_L}{w_H}\frac{\zeta}{1-\zeta}$, and the factor demands of H and L that depend on output and relative wages,

$$H(\bar{x}, w_L, w_H) = \bar{x}\zeta\left(\frac{w_L}{w_H}\right)^{1-\zeta}, \qquad L(\bar{x}, w_L, w_H) = \bar{x}(1-\zeta)\left(\frac{w_H}{w_L}\right)^{\zeta}.$$

Define k as the minimum unit cost to produce $\bar{x}$, total costs of producing $\bar{x}$ can be written as $k\bar{x} = w_L L + w_H H$. Plugging in $H(\bar{x}, w_L, w_H)$ and $L(\bar{x}, w_L, w_H)$, and rearranging provides the formulation of minimum unit costs, $k = w_L\left(\frac{w_H}{w_L}\right)^{\zeta}$.

1.7.3 Derivation of Firm's Optimality Conditions

The first order maximization conditions derived from (1.4) are:

$$\frac{\partial \Pi}{\partial N} = 0 \iff \beta A^{1-\beta} Y^{\beta-1}\frac{\partial Y}{\partial N} = k_N x_N, \tag{A1.1}$$

$$\frac{\partial \Pi}{\partial x_j} = 0 \quad \forall j \in [0,N] \iff \beta A^{1-\beta} Y^{\beta-1}\frac{\partial Y}{\partial x_j} = k_j \quad \forall j \in [0,N]. \tag{A1.2}$$

Combining (A1.1) and (A1.2) for some j results in

$$\frac{\frac{\partial Y}{\partial N}}{\frac{\partial Y}{\partial x_j}} = \frac{k_N x_N}{k_j} \quad \forall\, j \in [0,N]. \tag{A1.3}$$

From the definition of Y I calculate

$$\frac{\partial Y}{\partial N} = \frac{Y}{N}\left[\kappa + 1 - \frac{1+\sigma}{\sigma} + \frac{N x_N^{\frac{\sigma}{1+\sigma}}}{\frac{\sigma}{1+\sigma}\int_0^N x_j^{\frac{\sigma}{1+\sigma}} dj}\right], \tag{A1.4}$$

$$\frac{\partial Y}{\partial x_j} = \frac{x_j^{\frac{-1}{1+\sigma}} Y}{\int_0^N x_j^{\frac{\sigma}{1+\sigma}} dj}. \tag{A1.5}$$

Using (A1.5) in (A1.2), I obtain, for each pair (j, j'),

$$\frac{x_j}{x_{j'}} = \left[\frac{k'_j}{k_j}\right]^{1+\sigma}. \tag{A1.6}$$

Plugging (A1.6) back in (A1.5) results in $\frac{\partial Y}{\partial x_j} = \frac{x_j^{-1} Y}{k_j^{\sigma}\int_0^N k_j^{-\sigma} dj}$. Similarly, combining (A1.6) and (A1.4) results in

$$\frac{\partial Y}{\partial N} = \frac{Y}{N}\left[\kappa + 1 - \frac{1+\sigma}{\sigma} + \frac{N x_N^{\frac{\sigma}{1+\sigma}}}{\frac{\sigma}{1+\sigma} x_j^{\frac{\sigma}{1+\sigma}} k_j^{\sigma}\int_0^N k_j^{-\sigma} dj}\right]. \tag{A1.7}$$

Plugging the last two expressions in (A1.3), I obtain a non-linear expression for x_j:

$$x_j\left(\kappa - \frac{1}{\sigma}\right) k_j^{\sigma} \underbrace{\frac{1}{N}\int_0^N k_j^{-\sigma} dj}_{\equiv \bar{K}_N^{-\sigma}} + x_j^{\frac{1}{1+\sigma}} x_N^{\frac{\sigma}{1+\sigma}} \frac{1+\sigma}{\sigma} = \frac{x_N k_N}{k_j}. \tag{A1.8}$$

(A1.8) again holds for all $j \in [0, N]$. For $j = N$ an implicit expression for the optimal choice of N is obtained:

$$\left(\kappa - \frac{1}{\sigma}\right) k_N^{\sigma} \bar{K}_N^{-\sigma} = -\sigma \tag{A1.9}$$

Simple manipulations lead to

$$\kappa = \frac{1}{\sigma} - \underbrace{\frac{1}{\sigma}\frac{k_N^{-\sigma}}{\frac{1}{N}\int_0^N k_j^{-\sigma} dj}}_{=\left(N\frac{\partial \bar{K}_N}{\partial N}\right)/\bar{K}_N}, \tag{A1.10}$$

what is equation (1.5) in the main text. Consider next the optimal choice of x_j. Dividing (A1.8) by x_N and using (A1.6) enables me to rewrite x_j as

$$x_j = k_j^{-1-\sigma} k_N x_N \bar{K}_N^{\sigma} \frac{1}{1-\kappa\sigma}. \tag{A1.11}$$

Using this expression in the production function results in $Y = N^{\kappa+1} k_N x_N \bar{K}_N^{-1} \frac{1}{1-\kappa\sigma}$. In order to use this result in the FOCs, I rewrite $\frac{\partial Y}{\partial x_j}$ in (A1.5) using (A1.11), $\frac{\partial Y}{\partial x_j} = Y N^{-1} k_j k_N^{-1} x_N^{-1}(1-\kappa\sigma)$. Combining this expression with (A1.2) leads to the optimal demand for x_N, $x_N = \beta^{\frac{1}{1-\beta}} A N^{\frac{\beta(\kappa+1)-1}{1-\beta}} k_N^{-1} \bar{K}_N^{-\frac{\beta}{(1-\beta)}}(1-\kappa\sigma)$. Substituting with this expression in (A1.11), I obtain the optimal demand for each j, $x_j = \beta^{\frac{1}{1-\beta}} A N^{\frac{\beta(\kappa+1)-1}{1-\beta}} \bar{K}_N^{\sigma-\frac{\beta}{1-\beta}} k_j^{-1-\sigma}$. This is (1.6) in the main text. Taking to the power of $\frac{\sigma}{1+\sigma}$, integrating from 0 to N, dividing through N and taking to the power of $\frac{1+\sigma}{\sigma}$ results in

$$\left(\frac{1}{N}\int_0^N x_j^{\frac{\sigma}{1+\sigma}} dj\right)^{\frac{1+\sigma}{\sigma}} = A\left(\frac{\beta N^{\beta(\kappa+1)}}{N\bar{K}_N}\right)^{\frac{1}{1-\beta}}. \tag{A1.12}$$

Multiplying (A1.12) by N and $\bar{K}_N$ results in $N\bar{K}_N \left(\frac{1}{N}\int_0^N x_j^{\frac{\sigma}{1+\sigma}} dj\right)^{\frac{1+\sigma}{\sigma}} = A\beta^{\frac{1}{1-\beta}} N^{\frac{\beta\kappa}{1-\beta}} \bar{K}_N^{\frac{-\beta}{1-\beta}}$ where the RHS equals the RHS in $C(Y) = \int_0^N k_j x_j dj = A\beta^{\frac{1}{1-\beta}} N^{\frac{\beta\kappa}{1-\beta}} \bar{K}_N^{\frac{-\beta}{1-\beta}}$ and, thus, $N\bar{K}_N \left(\frac{1}{N}\int_0^N x_j^{\frac{\sigma}{1+\sigma}} dj\right)^{\frac{1+\sigma}{\sigma}} = C(Y)$. The demand for the last, or marginal, intermediate input $j = N$ can be simplified by rewriting k_N in terms of K_N (using (1.5) and $j = N$ in (1.6)):

$$x_N = \beta^{\frac{1}{1-\beta}} A N^{\frac{\beta(\kappa+1)-1}{1-\beta}} \bar{K}_N^{-\frac{1}{1-\beta}} (1-\kappa\sigma)^{\frac{1+\sigma}{\sigma}}. \tag{A1.13}$$

Multiplying (A1.12) by $N^{\kappa+1-\frac{1+\sigma}{\sigma}}$ results in the output of a firm: $Y = \beta^{\frac{1}{1-\beta}} A N^{\frac{\kappa}{1-\beta}} \bar{K}_N^{-\frac{1}{1-\beta}}$. This is (1.7) in the main text.

1.7.4 Properties of the Elasticity of Average Unit Costs

General minimum unit costs

The first derivative of average unit costs, $\bar{K}_N \equiv \left[\frac{1}{N}\int_0^N k_j^{-\sigma} dj\right]^{-\frac{1}{\sigma}}$, reads as $\frac{\partial \bar{K}_N}{\partial N} = \frac{\bar{K}_N}{\sigma}\left(\frac{1}{N} - \frac{k_N^{-\sigma}}{\int_0^N k_j^{-\sigma} dj}\right)$ and, consequently, the elasticity of average unit costs is $\varepsilon_{\bar{K}_N} =$

$\frac{\partial \bar{K}_N}{\partial N}\frac{N}{\bar{K}_N} = \frac{1}{\sigma} - \frac{N}{\sigma}\frac{k_N^{-\sigma}}{\int_0^N k_j^{-\sigma}dj}$. Its first derivative with respect to N is

$$\frac{\partial \varepsilon_{\bar{K}_N}}{\partial N} = \frac{k_N^{-\sigma}}{N\sigma \bar{K}_N^{-2\sigma}}\left[k_N^{-\sigma} + \bar{K}_N^{-\sigma}\left(\underbrace{\frac{N}{k_N}\frac{\partial k_N}{\partial N}}_{\equiv \varepsilon_{k_N}}\sigma - 1\right)\right]$$

which is strictly positive if and only if $k_N\left(1-\varepsilon_{k_N}\sigma\right)^{\frac{1}{\sigma}} > \bar{K}_N \iff \varepsilon_{k_N} > \varepsilon_{\bar{K}_N}$. The respective elasticities are defined as the change in percentage of k_N ($\bar{K}_N$) in reaction to a one percent change in N. Since $\bar{K}_N$ constitutes an average, it contains all minimum unit costs. Adding k_{N^+} (with $N^+ = N + \delta$, $\delta > 0$) increases $\bar{K}_N$ less in terms of percentage than this increases k_N (to k_{N^+}) in percents. Consequently, $\varepsilon_{k_N} > \varepsilon_{\bar{K}_N}$ and $\frac{\partial \varepsilon_{\bar{K}_N}}{\partial N} > 0$.

Cobb-Douglas specific minimum unit costs

Given Cobb-Douglas production of intermediates, minimum unit costs are provided by (1.3) and the elasticity of average minimum unit costs with respect to N becomes $\varepsilon_{\bar{K}_N} = \frac{1}{\sigma} - \frac{\frac{N}{\mu}\ln\bar{w}}{\bar{w}^{\sigma\frac{N}{\mu}}-1}$. Taking the first derivative with respect to N results in

$$\frac{\partial \varepsilon_{\bar{K}_N}}{\partial N} = \frac{\ln\bar{w}}{\mu\left(\bar{w}^{\sigma\frac{N}{\mu}}-1\right)^2}\left(\sigma\frac{N}{\mu}\ln\bar{w}\bar{w}^{\sigma\frac{N}{\mu}} - \bar{w}^{\sigma\frac{N}{\mu}} + 1\right)$$

which is positive if and only if $e^{\nu} > 1+\nu, \quad \nu \equiv -\sigma\frac{N}{\mu}\ln\bar{w}$. Similarly, the first derivative with respect to $\bar{w}$ (keeping N constant) results in

$$\frac{\partial \varepsilon_{\bar{K}_N}}{\partial \bar{w}} = \frac{N}{\mu\bar{w}\left(\bar{w}^{\sigma\frac{N}{\mu}}-1\right)^2}\left(\sigma\frac{N}{\mu}\ln\bar{w}\bar{w}^{\sigma\frac{N}{\mu}} - \bar{w}^{\sigma\frac{N}{\mu}} + 1\right)$$

which is equally positive if and only if $e^{\nu} > 1+\nu$. First, $e^{\nu} = 1+\nu$ for $\nu = 0$. Second, $\forall \nu < 0$, $\frac{\partial e^{\nu}}{\partial \nu} < \frac{(1+\nu)}{\partial \nu}$. It follows that, as e^{ν} and $1+\nu$ are strictly monotonously increasing functions, $e^{\nu} > 1+\nu \quad \forall \nu < 0$. Consequently, $\frac{\partial \varepsilon_{\bar{K}_N}}{\partial N} > 0$ and $\frac{\partial \varepsilon_{\bar{K}_N}}{\partial \bar{w}} > 0$ (keeping N constant in the latter).

1.7.5 Derivation of Production Factor Demands

Demand of high-skilled labor to produce intermediate input j, H_j, is given through cost minimization (see Appendix 1.7.2),

$$H_j = x_j \frac{j}{\mu} \bar{w}^{\frac{j}{\mu}-1} = \beta^{\frac{1}{1-\beta}} A N^{\frac{\beta(\kappa+1)-1}{1-\beta}} \bar{K}_N^{\sigma-\frac{\beta}{1-\beta}} w_L^{-1-\sigma} \frac{j}{\mu} \bar{w}^{-\sigma\frac{j}{\mu}-1}.$$

Taking the integral $\int_0^N dj$ and using $k_j = w_L \bar{w}^{\frac{j}{\mu}}$ leads to

$$H = \int_0^N H_j dj = \beta^{\frac{1}{1-\beta}} A N^{\frac{\beta(\kappa+1)-1}{1-\beta}} \bar{K}_N^{\sigma-\frac{\beta}{1-\beta}} w_L^{-1-\sigma} \frac{1}{\mu\bar{w}} \int_0^N j \bar{w}^{-\sigma\frac{j}{\mu}} dj$$

where integration by parts results in

$$H = \beta^{\frac{1}{1-\beta}} A N^{\frac{\beta(\kappa+1)-1}{1-\beta}} \bar{K}_N^{\sigma-\frac{\beta}{1-\beta}} w_L^{-1-\sigma} \frac{\frac{1-\bar{w}^{-\frac{N}{\mu}\sigma}}{\ln \bar{w}^{\frac{\sigma}{\mu}}} - N\bar{w}^{-\frac{N}{\mu}\sigma}}{\sigma \bar{w} \ln \bar{w}}. \tag{A1.14}$$

Substituting for $\bar{w}^{\frac{N}{\mu}\sigma} - 1$ using (1.9) simplifies the above equality further to

$$H = \beta^{\frac{1}{1-\beta}} A N^{\frac{\beta\kappa}{1-\beta}} \bar{K}_N^{\sigma-\frac{\beta}{1-\beta}} w_L^{-1-\sigma} \bar{w}^{-\frac{N}{\mu}\sigma-1} (\ln \bar{w})^{-1} \frac{\kappa}{1-\kappa\sigma}. \tag{A1.15}$$

Similarly, L_j is given by

$$\begin{aligned} L_j &= x_j(1-\frac{j}{\mu})\bar{w}^{\frac{j}{\mu}} = \beta^{\frac{1}{1-\beta}} A N^{\frac{\beta(\kappa+1)-1}{1-\beta}} \bar{K}_N^{\sigma-\frac{\beta}{1-\beta}} w_L^{-1-\sigma} \left(1-\frac{j}{\mu}\right) \bar{w}^{-\frac{j}{\mu}\sigma} \\ \text{and} \quad L &= \int_0^N L_j dj = \beta^{\frac{1}{1-\beta}} A N^{\frac{\beta(\kappa+1)-1}{1-\beta}} \bar{K}_N^{\sigma-\frac{\beta}{1-\beta}} w_L^{-1-\sigma} \int_0^N \bar{w}^{-\frac{j}{\mu}\sigma} dj - \bar{w}H, \end{aligned}$$

where integrating and using the expression in (A1.14) for H results in

$$L = \beta^{\frac{1}{1-\beta}} A N^{\frac{\beta(\kappa+1)-1}{1-\beta}} \bar{K}_N^{\sigma-\frac{\beta}{1-\beta}} w_L^{-1-\sigma} \frac{\mu\left(1-\bar{w}^{-\frac{N}{\mu}\sigma}\right)\left(1-\frac{1}{\sigma\ln\bar{w}}\right) + N\bar{w}^{-\frac{N}{\mu}\sigma}}{\sigma \ln \bar{w}}.$$

Again, substituting for $\bar{w}^{\frac{N}{\mu}\sigma} - 1$ and using (1.9) results in

$$L = \beta^{\frac{1}{1-\beta}} A N^{\frac{\beta\kappa}{1-\beta}} \bar{K}_N^{\sigma-\frac{\beta}{1-\beta}} w_L^{-1-\sigma} \bar{w}^{-\frac{N}{\mu}\sigma} \frac{\ln \bar{w} - \kappa}{\ln \bar{w}(1-\kappa\sigma)}. \tag{A1.16}$$

Relative production labor demands:

Dividing (A1.15) by (A1.16) involves directly $\frac{H}{L} = \frac{1}{\bar{w}} \frac{\kappa}{\ln \bar{w} - \kappa}$.

1.7.6 Proofs for Firm Decisions Given Wages and Market Size

Proof of Lemma 1.1

A firm's optimal choice of the level of technology in production, N^*, given $\bar{w}$ is a solution to (1.9):

$$\underbrace{\bar{w}^{\sigma \frac{N}{\mu}} - 1}_{f(N,\bar{w})} = \underbrace{\frac{\sigma \frac{N}{\mu} \ln \bar{w}}{1 - \kappa\sigma}}_{g(N,\bar{w})}.$$

I start proofing the existence of a unique equilibrium $N^*(\bar{w})$ given $\bar{w}$ by showing that there exist optimal technology levels $\forall \bar{w} \in (1, \infty)$ and subsequently establish uniqueness. Applying L'Hôpital's Rule, the following holds $\forall \bar{w} \in (1, \infty)$:

$$\begin{aligned}
\lim_{N \to 0} \frac{f(N,\bar{w})}{g(N,\bar{w})} &= \lim_{N \to 0} \frac{\frac{\partial f(N,\bar{w})}{\partial N}}{\frac{\partial g(N,\bar{w})}{\partial N}} = 0 < 1 \\
\lim_{N \to +\infty} \frac{f(N,\bar{w})}{g(N,\bar{w})} &= \lim_{N \to +\infty} \frac{\frac{\partial f(N,\bar{w})}{\partial N}}{\frac{\partial g(N,\bar{w})}{\partial N}} = +\infty > 1.
\end{aligned}$$

Since $f(N)$ and $g(N)$ are continuous, $\forall \bar{w} \in (1, \infty)$ $\exists N^* \in (0, \infty)$ such that $f(N^*, \bar{w}) = g(N^*, \bar{w})$. Moreover, it is immediate that $f(N)$ is a strictly convex and $g(N)$ is a linear function. Consequently, the fact that $f(N)$ and $g(N)$ intersect implies that they intersect twice for a given $\bar{w}$, as I abstract from a tangent solution. First, they intersect at $N^* = 0$ $\forall \bar{w} \in (1, \infty)$. Second, since I impose $N^* > 0$, $N^* \in (0, \infty)$ is a unique choice of the level of technology in production $\forall \bar{w} \in (1, \infty)$.

Furthermore, $\forall N \geq N^*$ it holds that $f(N) \geq g(N)$ and $\frac{\partial f(N,\bar{w})}{\partial N} > \frac{\partial g(N,\bar{w})}{\partial N}$.

Proof of Lemma 1.2

Proof of $N \leq \mu$:

The level of technology, N, is given implicitly. A second order Taylor approximation[35] results in $N \approx \frac{2\kappa\mu}{(1-\kappa\sigma)\ln\bar{w}}$ where N exhibits qualitatively all comparative statics' properties. From the above approximation, $N \leq \mu$ if and only if $\frac{2\kappa}{(1-\kappa\sigma)\ln\bar{w}} \leq 1$ which implies $\bar{w} \geq e^{\frac{2\kappa}{(1-\kappa\sigma)}}$.

Proof of $N > 1$:

The assumption $e^{\kappa\mu} > \bar{w}$ can be rewritten as $\frac{\kappa\mu}{\ln\bar{w}} > 1$. Taking derivatives of f and g with respect to N leads to

$$\frac{\partial f}{\partial N} = \frac{\sigma}{\mu}\bar{w}^{\sigma\frac{N}{\mu}}\ln\bar{w}, \qquad \frac{\partial g}{\partial N} = \frac{\frac{\sigma}{\mu}\ln\bar{w}}{1-\kappa\sigma}.$$

As $\frac{\partial f}{\partial N} > 0$ and $\frac{\partial^2 f}{\partial N^2} > 0$, f is strictly convex in N. As $\frac{\partial g}{\partial N} > 0$ and $\frac{\partial^2 g}{\partial N^2} = 0$, g is linear in N with a positive slope. For $N = 0$, f and g would be zero. For $N^{+} \to 0$, $\frac{\partial f}{\partial N} < \frac{\partial g}{\partial N}$. Consequently, a necessary condition for an equilibrium value of N (N^*) is that partial derivatives evaluated at N^* satisfy: $\frac{\partial f}{\partial N}(N^*) > \frac{\partial g}{\partial N}(N^*)$. In the following, it is shown that $\frac{\partial f}{\partial N}(N = \frac{\kappa\mu}{\ln\bar{w}}) < \frac{\partial g}{\partial N}(N = \frac{\kappa\mu}{\ln\bar{w}})$ and consequently $N^* > \frac{\kappa\mu}{\ln\bar{w}}$. Evaluating first derivatives at $N = \frac{\kappa\mu}{\ln\bar{w}}$ results in

$$\frac{\partial f}{\partial N} = \frac{\sigma}{\mu}\ln\bar{w}e^{\kappa\sigma}, \qquad \frac{\partial g}{\partial N} = \frac{\sigma}{\mu}\ln\bar{w}(1-\kappa\sigma)^{-1}$$

which implies that $\frac{\partial f}{\partial N} < \frac{\partial g}{\partial N} \iff \kappa\sigma < -\ln(1-\kappa\sigma)$. As $-1 < \kappa\sigma < 0$, a Taylor expansion can be applied to $-\ln(1-\kappa\sigma)$ which transforms $\kappa\sigma < -\ln(1-\kappa\sigma)$ into

$$\kappa\sigma < \kappa\sigma + \frac{1}{2}(\kappa\sigma)^2 + \frac{1}{3}(\kappa\sigma)^3 + \circ\left(\frac{1}{3}(\kappa\sigma)^3\right).$$

Consequently, $\partial f(N = \frac{\kappa\mu}{\ln\bar{w}})/\partial N < \partial g(N = \frac{\kappa\mu}{\ln\bar{w}})/\partial N$ for all admissible parameter values.

[35] Consequently, the presented restriction is an approximation.

Proof of Proposition 1.1

Proof of $dN/d\bar{w}$:

(1.9) determines implicitly a firm's choice of technology in production. Assume that N is a solution to (1.9). The reaction of N with respect to changes in the wage gap is computed by implicit differentiation: $\frac{dN}{d\bar{w}} = -\frac{\partial F}{\partial \bar{w}} / \frac{\partial F}{\partial N}$. From (1.9), define

$$F = \frac{\sigma \frac{N}{\mu} \ln \bar{w}}{1-\kappa\sigma} - \bar{w}^{\sigma \frac{N}{\mu}} + 1 = 0$$

and calculate partial derivatives:

$$\frac{\partial F}{\partial \bar{w}} = \frac{N}{\mu}\frac{\sigma}{\bar{w}}\left[\frac{1}{1-\kappa\sigma} - \bar{w}^{\sigma\frac{N}{\mu}}\right], \qquad \frac{\partial F}{\partial N} = \frac{\sigma}{\mu}\ln \bar{w}\left[\frac{1}{1-\kappa\sigma} - \bar{w}^{\sigma\frac{N}{\mu}}\right].$$

Combining and rearranging leads to $\frac{dN}{d\bar{w}} = -\frac{N}{\ln \bar{w} \quad \bar{w}} < 0$.

Proof of $dN/d\kappa$:

How the choice of technology in production reacts to a change in κ can again be determined by the implicit differentiation approach where $\frac{\partial F}{\partial \kappa} = \frac{N}{\mu} \ln \bar{w} \frac{(\sigma)^2}{(1-\kappa\sigma)^2}$. As a consequence,

$$\frac{dN}{d\kappa} = -\frac{\frac{\partial F}{\partial \kappa}}{\frac{\partial F}{\partial N}} = -\frac{N\sigma}{(1-\kappa\sigma)^2\left(\frac{1}{1-\kappa\sigma} - \bar{w}^{\sigma\frac{N}{\mu}}\right)}.$$

Replacing $\bar{w}^{\sigma\frac{N}{T}}$ from equation (1.9) leads to $\frac{dN}{d\kappa} = \frac{N}{(1-\kappa\sigma)\left(\frac{N}{\mu}\ln \bar{w} - \kappa\right)} > 0$ as Lemma 1.2 implies that $\frac{N}{\mu}\ln \bar{w} > \kappa$.

Proof of $dN/d\mu$:

The first derivative of F with respect to μ reads as $\frac{\partial F}{\partial \mu} = -\frac{N}{\mu^2}\sigma \ln \bar{w}\left[\frac{1}{1-\kappa\sigma} - \bar{w}^{\sigma\frac{N}{\mu}}\right]$. Thus,

$$\frac{dN}{d\mu} = -\frac{\frac{\partial F}{\partial \mu}}{\frac{\partial F}{\partial N}} = \frac{N}{\mu} > 0.$$

Proof of $\left(\partial \frac{x_{j+1}}{x_j}\right) / (\partial \bar{w})$:

The first derivative of relative intermediate inputs employment, $\frac{x_{j+1}}{x_j} = \bar{w}^{-\frac{1+\sigma}{\mu}}$, with respect to $\bar{w}$ is $\frac{\partial\left(\frac{x_{j+1}}{x_j}\right)}{\partial \bar{w}} = -\frac{1+\sigma}{\mu\bar{w}}\frac{x_{j+1}}{x_j} < 0.$

Proof of Proposition 1.2

Taking the first derivatives of (1.13) with respect to $\bar{w}$ and κ results in:

$$\frac{\partial\left(\frac{H}{L}\right)}{\partial \bar{w}} = -\frac{H}{L}\frac{1}{\bar{w}}\frac{\ln \bar{w} - \kappa + 1}{\ln \bar{w} - \kappa} < 0, \qquad \frac{\partial\left(\frac{H}{L}\right)}{\partial \kappa} = \frac{1}{\bar{w}}\frac{\ln \bar{w}}{(\ln \bar{w} - \kappa)^2} > 0.$$

Taking the derivative of $\frac{\partial\left(\frac{H}{L}\right)}{\partial \kappa}$ with respect to $\bar{w}$ gives $\frac{\partial^2\left(\frac{H}{L}\right)}{\partial \kappa \partial \bar{w}} = -\frac{1}{\bar{w}^2}\frac{\ln \bar{w}(\ln \bar{w} - \kappa) + \kappa}{(\ln \bar{w} - \kappa)^2} < 0.$

Proof of Proposition 1.3

Taking the first derivative of (1.14) with respect to $\bar{w}$ holding w_L constant and subsequent manipulating leads to $\frac{\partial \phi}{\partial \bar{w}} = -\frac{\kappa \phi}{\bar{w} \ln \bar{w}}$. Taking the first derivative of (1.14) with respect to κ holding w_L and $\bar{w}$ constant and subsequent manipulating leads to $\frac{\partial \phi}{\partial \kappa} = \ln(N)\phi > 0$ which holds as $\ln(N) > 1$ is implied by *Lemma 1.2*.

Proof of Lemma 1.3

The derivative of productivity differences (1.16) with respect to the skill premium and subsequent manipulating reads as $\frac{\partial \phi_\Delta}{\partial \bar{w}} = -\phi_\Delta \frac{\kappa_m - \kappa_d}{\bar{w} \ln \bar{w}} < 0.$

1.7.7 Proofs for Closed Economy

Note that within this section, I abstract from the index c that denotes closed economy variables for reasons of readability.

Proof of Lemma 1.4

Define

$$\underbrace{\frac{H^s}{L^s}\bar{w}}_{\equiv u(\bar{w})} = \underbrace{\frac{\kappa}{\frac{\ln \bar{w}}{\beta} - \kappa}}_{\equiv v(\bar{w})}.$$

First, $\bar{w} > 0$ as w_H and w_L are strictly positive. Moreover, $\forall$ $\bar{w}$ such that $0 < \bar{w} < e^{\kappa_d \beta}, u(\bar{w}) > v(\bar{w})$. Consequently, if there exists any solution to (1.21), $\bar{w}^*$, $\bar{w}^* > e^{\kappa_d \beta}$.

$\forall \bar{w} > e^{\kappa_d \beta}$, $u(\bar{w})$ is strictly monotonously increasing in $\bar{w}$ and $v(\bar{w})$ is strictly monotonously decreasing in $\bar{w}$. Furthermore, $\forall \bar{w} > e^{\kappa_d \beta}$ it holds that

$$\lim_{\bar{w} \to e^{\kappa_d \beta}} u(\bar{w}) < \lim_{\bar{w} \to e^{\kappa_d \beta}} v(\bar{w}), \qquad \lim_{\bar{w} \to \infty} u(\bar{w}) > \lim_{\bar{w} \to \infty} v(\bar{w}).$$

Consequently, $\forall \bar{w} > 0$ $\exists!$ $\bar{w}^*$. It holds that $\bar{w}^* > e^{\kappa_d \beta}$.

Proof of Proposition 1.4

Define $G_c = \frac{H^s}{L^s}\bar{w} - \frac{\kappa_d}{\frac{\ln \bar{w}}{\beta} - \kappa_d} = 0$. First derivatives are

$$\frac{\partial G_c}{\partial \bar{w}} = \frac{H^s}{L^s} + \frac{1}{\bar{w}} \frac{\frac{\kappa_d}{\beta}}{(\frac{\ln \bar{w}}{\beta} - \kappa_d)^2}, \qquad \frac{\partial G_c}{\partial \kappa_d} = -\frac{\frac{\ln \bar{w}}{\beta}}{(\frac{\ln \bar{w}}{\beta} - \kappa_d)^2}, \qquad \frac{\partial G_c}{\partial \beta} = -\frac{\kappa_d \ln \bar{w}}{(\frac{\ln \bar{w}}{\beta} - \kappa_d)^2}.$$

As a consequence,

$$\begin{aligned} \frac{d\bar{w}}{d\left(\frac{H^s}{L^s}\right)} &= -\frac{\frac{\partial G_c}{\partial\left(\frac{H^s}{L^s}\right)}}{\frac{\partial G_c}{\partial \bar{w}}} = -\frac{\bar{w}}{\frac{H^s}{L^s} + \frac{1}{\bar{w}} \frac{\frac{\kappa_d}{\beta}}{(\frac{\ln \bar{w}}{\beta} - \kappa_d)^2}} < 0, \\ \frac{d\bar{w}}{d\kappa_d} &= -\frac{\frac{\partial G_c}{\partial \kappa}}{\frac{\partial G_c}{\partial \bar{w}}} = \frac{\bar{w} \ln \bar{w}}{\kappa_d(\ln \bar{w} - \kappa_d \beta + 1)} > 0, \\ \frac{d\bar{w}}{d\beta} &= -\frac{\frac{\partial G_c}{\partial \beta}}{\frac{\partial G_c}{\partial \bar{w}}} = \frac{\beta \bar{w} \ln \bar{w}}{\ln \bar{w} - \kappa_d \beta + 1} > 0. \end{aligned}$$

Proof of Proposition 1.5

Proof that $dN/d\mu$:

From *Proposition 1.2*, $N \approx \frac{2\kappa_d \mu}{(1-\kappa_d \sigma) \ln \bar{w}}$. The restriction $N/\mu \leq 1$ does not bind if and only if $\bar{w} \geq \exp\left(\frac{2\kappa_d}{1-\kappa_d \sigma}\right)$. Define a threshold skill premium: $\bar{w}^\circ = \exp\left(\frac{2\kappa_d}{1-\kappa_d \sigma}\right)$. Let's further define the functions

$$\underbrace{\frac{H^s}{L^s}\bar{w}}_{\equiv x(\bar{w})} = \underbrace{\frac{\kappa_d}{\frac{\ln \bar{w}}{\beta} - \kappa_d}}_{\equiv y(\bar{w})} \tag{A1.17}$$

where $x(\bar{w})$ is a linear and strictly monotone increasing and $y(\bar{w})$ is a strictly decreasing function for $\bar{w} > e^{\kappa_d \beta}$. The equilibrium value of $\bar{w}$ is defined as $\bar{w}^*$ what implies $x(\bar{w}^*) = y(\bar{w}^*)$. Furthermore, $\lim_{\bar{w}\to e^{\kappa_d\beta}} x(\bar{w}) < \lim_{\bar{w}\to e^{\kappa_d\beta}} y(\bar{w})$. Therefore, $\forall e^{\kappa_d\beta} < \bar{w} \leq \bar{w}^*$ it holds that $x(\bar{w}) \leq y(\bar{w})$ while $\forall \bar{w} \geq \bar{w}^*$ it is true that $x(\bar{w}) \geq y(\bar{w})$. Plugging the threshold value $\bar{w}^\circ$ into equation (A1.17) under the assumption that $x(\bar{w}^\circ) \leq y(\bar{w}^\circ)$ results, as a consequence, in a parameter combination that ensures $\bar{w}^* \geq \bar{w}^\circ$. Consequently, the restriction $N/\mu \leq 1$ does not bind if and only if

$$\frac{H^s}{L^s} \leq \underbrace{\exp\left(\frac{-2\kappa_d}{1-\kappa_d\sigma}\right)}_{<1} \underbrace{\frac{1-\kappa_d\sigma}{\frac{2}{\beta}-1+\kappa_d\sigma}}_{<1}.$$

<u>Proof that $e^{\kappa_d\mu} > \bar{w}$:</u>

Given $\bar{w}$, *Lemma 1.2* states that if $e^{\kappa_d\mu} > \bar{w}$ than $N > 1$. $\forall \bar{w} > \bar{w}^*$, where $\bar{w}^*$ is the equilibrium skill premium from (1.21), it holds that $\bar{w}\frac{H^s}{L^s}$ (LHS of (1.21)) is greater than $\frac{\kappa_d}{\ln \bar{w}/\beta - \kappa_d}$ (RHS of (1.21)). Plugging $e^{\kappa\mu}$ into (1.21) results in $e^{\kappa_d\mu}\frac{H^s}{L^s} > \frac{\kappa_d}{\frac{\kappa_d\mu}{\beta}-\kappa_d} \iff \kappa > \frac{\ln\left(\frac{\beta}{\mu-\beta}\frac{L^s}{H^s}\right)}{\mu}$ which always holds if μ is chosen high enough.

1.7.8 Proofs for Open Economy

Note that within this section I will abstract from the index o that denotes open economy variables for reasons of readability.

Proof of Proposition 1.6

The left hand side of the skill premium equations (1.21) and (1.28) are identical in their functional forms and strictly monotonously increasing in $\bar{w}$. It is evident that the right hand side of (1.21) is strictly decreasing in $\bar{w}$. In the following, I show that the right hand side of (1.28) is also strictly decreasing in $\bar{w}$:

$$
\begin{aligned}
&\frac{\partial \text{RHS of (1.28)}}{\partial \bar{w}} < 0 \iff \\
&\left(\text{denominator of RHS of (1.28)}\right)\left(\kappa_d \frac{(1-\beta)}{f_d}\bar{w}H^s - (\kappa_m - \kappa_d)^2 \frac{M_m}{\ln(\bar{w})}\frac{\beta}{1-\beta}\phi_\Delta^{\frac{\beta}{1-\beta}}\right) - \\
&\left(\text{nominator of RHS of (1.28)}\right)\left(\frac{(1-\beta)}{f_d\beta}\left(L^s + \bar{w}H^s\right) + \left(\frac{\ln(\bar{w})}{\beta} - \kappa_d\right)\frac{(1-\beta)}{f_d}\bar{w}H^s\right. \\
&\left.+(\kappa_m - \kappa_d)^2 \frac{\beta}{1-\beta}\phi_\Delta^{\frac{\beta}{1-\beta}}\frac{M_m}{\ln(\bar{w})} + \phi_\Delta^{\frac{\beta}{1-\beta}}(\kappa_m - \kappa_d)M_m - \phi_\Delta^{\frac{\beta}{1-\beta}}\frac{1-\beta}{\beta}M_m + \frac{f_m}{f_d}\frac{1-\beta}{\beta}M_m\right) < 0 \\
&\iff -\frac{\kappa_d M_m \ln(\bar{w})\bar{w}H^s(1-\beta)^2}{f_d\beta}\left(\phi_\Delta^{\frac{\beta}{1-\beta}} - \frac{f_m}{f_d}\right) \\
&-\frac{(\kappa_m - \kappa_d)(1-\beta)\phi_\Delta^{\frac{\beta}{1-\beta}}M_m^2}{\beta}\left(\frac{L^s + \bar{w}H^s}{f_d M_m} - \phi_\Delta^{\frac{\beta}{1-\beta}}\right) \\
&-\frac{\kappa_d(1-\beta)^2 M_m}{f_d\beta}\left(L^s + \bar{w}H^s\right)\left(\frac{L^s + \bar{w}H^s}{f_d M_m} - \phi_\Delta^{\frac{\beta}{1-\beta}}\right) - \Sigma < 0,
\end{aligned}
$$

where $\Sigma = (\kappa_m - \kappa_d)\phi_\Delta^{\frac{\beta}{1-\beta}}\frac{M_m}{f_d}\Big((\kappa_m - \kappa_d)\left(L^s + \bar{w}H^s + f_m M_m\right) + \kappa_d(1-\beta)\left(L^s + 2\bar{w}H^s\right) + \left(\frac{\ln(\bar{w})}{\beta} - \kappa_d\right)(1-\beta)\bar{w}H^s + \frac{1-\beta}{\beta}f_m M_m\Big) + \frac{\kappa_d(L^s + \bar{w}H^s)(1-\beta)^2 f_m M_m}{f_d^2\beta} > 0$. Production is profitable for a multinational firm if and only if $p_m Y_m \geq w_L f_m$. Free entry for domestic firms implies that $p_d Y_d = w_L f_d$. Dividing the former inequality by the latter equality leads to $\phi_\Delta^{\frac{\beta}{1-\beta}} \geq \frac{f_m}{f_d}$. A positive number of domestic firms being in the market implies that $\frac{(1-\beta)(L^s + \bar{w}H^s)}{M_m f_d} > \phi_\Delta^{\frac{\beta}{1-\beta}}$ (see (1.27)). As a consequence, $\frac{\partial \text{RHS of (1.28)}}{\partial \bar{w}} < 0$. Furthermore, the RHS of (1.28) is above the RHS of (1.21) if and only if:

$$
\begin{aligned}
&\frac{\kappa_d\frac{(1-\beta)}{f_d}\left(L^S + \bar{w}^o H^S\right) + (\kappa_m - \kappa_d)\phi_\Delta^{\frac{\beta}{1-\beta}}M_m}{\left(\frac{\ln(\bar{w}^o)}{\beta} - \kappa_d\right)\frac{(1-\beta)}{f_d}\left(L^S + \bar{w}^o H^S\right) - (\kappa_m - \kappa_d)\phi_\Delta^{\frac{\beta}{1-\beta}}M_m - \left(\phi_\Delta^{\frac{\beta}{1-\beta}} - \frac{f_m}{f_d}\right)\frac{1-\beta}{\beta}\ln(\bar{w}^o)M_m} \\
&> \frac{\kappa_d}{\frac{\ln(\bar{w})}{\beta} - \kappa_d} \\
\iff\quad &(\kappa_m - \kappa_d)\phi_\Delta^{\frac{\beta}{1-\beta}} > \kappa_d(1-\beta)\left(\frac{f_m}{f_d} - \phi_\Delta^{\frac{\beta}{1-\beta}}\right).
\end{aligned}
$$

This is true for all parameter combinations. The skill premium in closed and open economy is uniquely given by the intersection of the LHS (strictly increasing and of range $[0, \infty)$) and RHS (strictly decreasing and of range (∞, c), $0 < c < \infty$) of (1.21) and (1.28), respectively. As the RHS of (1.28) is for all parameter combinations strictly above the RHS of (1.21), the skill premium in open economy is for all feasible parameter combinations greater than in closed economy. All parameter combinations that imply zero profits for domestic firms and zero or positive profits for foreign firms are feasible.

Proof of Proposition 1.7

Existence proof:

According to *Lemma 1.3*, the LHS of (1.29) decreases strictly monotonously in $\bar{w}$; as the RHS is unaffected by $\bar{w}$, there exists at most one equilibrium value of $\bar{w}$. Furthermore, from *Proposition 1.6* it is known that $\bar{w}_c$ constitutes a lower bound to $\bar{w}_o$ where $\bar{w}_o$ is the skill premium in open and $\bar{w}_c$ that in closed economy. Rewriting (1.21) leads to $e^{\ln(\bar{w}_c)}\left(\frac{\ln(\bar{w}_c)}{\beta} - \kappa_d\right) = \kappa_d \frac{L^s}{H^s}$ where a first order Taylor approximation of $e^{\ln(\bar{w})}$ and manipulating results in $\frac{\ln(\bar{w})^2}{\beta} + \left(\frac{1}{\beta} - \kappa_d\right)\ln(\bar{w}) - \kappa_d\left(1 + \frac{L^s}{H^s}\right) \approx 0$. As one of the two solutions to the above quadratic equation implies a $\ln(\bar{w}) < 0$, the only admissible one is

$$\bar{w} = \exp\left[\frac{\beta}{2}\left(\left(\frac{1}{\beta} - \kappa_d\right)^2 + \frac{4}{\beta}\kappa_d\left(1 + \frac{L^s}{H^s}\right)\right)^{\frac{1}{2}} - \frac{1}{2} + \frac{\kappa_d \beta}{2}\right] \equiv \chi.$$

Consequently, as long as $\phi_\Delta(\chi)^{\frac{\beta}{1-\beta}} \geq \frac{f_m}{f_d}$ $\left(\phi_\Delta(\bar{w}_c)^{\frac{\beta}{1-\beta}} \geq \frac{f_m}{f_d}\right)$ there exists a $\bar{w}_o > \bar{w}_c$ such that $\phi_\Delta(\bar{w}_o)^{\frac{\beta}{1-\beta}} = \frac{f_m}{f_d}$.

Proof of skill premium comparative statics:

Define $G = \phi_\Delta^{\frac{\beta}{1-\beta}} - \frac{f_m}{f_d}$. First derivatives with respect to $\bar{w}$ and κ_m are

$$\frac{\partial G}{\partial \bar{w}} = -\frac{\beta}{1-\beta}\phi_\Delta^{\frac{\beta}{1-\beta}} \frac{\kappa_m - \kappa_d}{\bar{w}\ln\bar{w}} < 0, \qquad \frac{\partial G}{\partial \kappa_m} = \frac{\beta}{1-\beta}\phi_\Delta^{\frac{\beta}{1-\beta}} \ln(N_m) > 0.$$

This implies

$$\frac{d\bar{w}}{d\kappa_m} = -\frac{\frac{\partial G}{\partial \kappa_m}}{\frac{\partial G}{\partial \bar{w}}} = \frac{\ln(N_m)\bar{w}\ln(\bar{w})}{\kappa_m - \kappa_d} > 0.$$

The first derivative with respect to κ_d is $\frac{\partial G}{\partial \kappa_d} = -\frac{\beta}{1-\beta}\phi_\Delta^{\frac{\beta}{1-\beta}} \ln(N_d) < 0$ which implies

$$\frac{d\bar{w}}{d\kappa_d} = -\frac{\frac{\partial G}{\partial \kappa_d}}{\frac{\partial G}{\partial \bar{w}}} = -\frac{\ln(N_d)\bar{w}\ln(\bar{w})}{\kappa_m - \kappa_d} < 0.$$

As $\frac{\partial G}{\partial\left(\frac{f_m}{f_d}\right)} = -1 < 0$,

$$\frac{d\bar{w}}{d\left(\frac{f_m}{f_d}\right)} = -\frac{\frac{\partial G}{\partial\left(\frac{f_m}{f_d}\right)}}{\frac{\partial G}{\partial \bar{w}}} = -\frac{1-\beta}{\beta}\phi_{\Delta}^{\frac{\beta}{\beta-1}}\frac{\bar{w}\ln(\bar{w})}{\kappa_m - \kappa_d} < 0.$$

Proof of Lemma 1.5

Proof of the number of domestic firms:

The partial derivative of M_d with respect to κ_d reads as

$$\begin{aligned}\frac{\partial M_d}{\partial \kappa_d} &= \frac{1-\beta}{f_d(\kappa_m-\kappa_d)^2}\Bigg[\ln(N_d)\bar{w}\ln\bar{w}\left(H^s\left(\frac{\ln(\bar{w})}{\beta}-\kappa_m\right)+\frac{H^s}{\beta}\right)\\ &\quad+\left(\kappa_m L^S - \bar{w}H^S\left(\frac{\ln(\bar{w})}{\beta}-\kappa_m\right)\right)\Bigg] > 0\end{aligned}$$

since $\kappa_m L^S - \bar{w}H^S\left(\frac{\ln(\bar{w})}{\beta}-\kappa_m\right) > 0$ if $M_d > 0$. The partial derivative of M_d with respect to $\frac{f_m}{f_d}$ given f_d is

$$\frac{\partial M_d}{\partial\left(\frac{f_m}{f_d}\right)} = -\frac{1-\beta}{f_d(\kappa_m-\kappa_d)}\frac{d\bar{w}}{d\left(\frac{f_m}{f_d}\right)}\left[\left(H^s\frac{\ln(\bar{w})}{\beta}-\kappa_m\right)+\frac{H^s}{\beta}\right] > 0,$$

as $\frac{d\bar{w}}{d\left(\frac{f_m}{f_d}\right)} < 0$ from *Proposition 1.7*. Finally, the partial derivative of M_d with respect to κ_m is

$$\begin{aligned}\frac{\partial M_d}{\partial \kappa_m} &= \frac{1-\beta}{f_d(\kappa_m-\kappa_d)^2}\Bigg[(\kappa_m-\kappa_d)\left(L^s - \frac{d\bar{w}}{d\kappa_m}H^s\left(\frac{\ln(\bar{w})}{\beta}-\kappa_m\right)-\frac{H^s}{\beta}\frac{d\bar{w}}{d\kappa_m}+\bar{w}H^s\right)\\ &\quad-\kappa_m L^S + \bar{w}H^S\left(\frac{\ln(\bar{w})}{\beta}-\kappa_m\right)\Bigg] < 0\\ \iff \quad &\frac{H^s}{L^s} < \frac{\beta\kappa_d\left(1+\bar{w}\frac{H^s}{L^s}\right)}{\ln(\bar{w})\bar{w}} + \ln(N_m)\Big(\ln(\bar{w})+1-\beta\kappa_m\Big).\end{aligned}$$

From (1.10), $N_m \approx \frac{2\kappa_m}{1-\kappa_m\sigma}\frac{\mu}{\ln\bar{w}_i}$. The highest wage level imposes the most negative effect on the choice of N_m, thus I impose $\bar{w}_i = \bar{w}_o$. However, since in this case $\bar{w}_i$ is independent of μ, μ can be chosen arbitrarily high, such that in particular $\ln(N_m) > 1$. A similar reasoning can be applied to $\ln(N_d) > 1$. Moreover, $\ln(\bar{w}) > \kappa_m$. As a consequence,

$\frac{\partial M_d}{\partial \kappa_m} < 0.$

Proof of the number of multinational firms:

The first partial derivative of M_m with respect to κ_m reads as

$$\begin{aligned}
\frac{\partial M_m}{\partial \kappa_m} &= \frac{1-\beta}{f_m(\kappa_m-\kappa_d)^2}\Bigg[(\kappa_m-\kappa_d)\left(\frac{d\bar{w}}{d\kappa_m}H^s\left(\frac{\ln(\bar{w})}{\beta}-\kappa_m\right)+\frac{H^s}{\beta}\frac{d\bar{w}}{d\kappa_m}\right)\\
&\quad -\left(\bar{w}H^s\left(\frac{\ln(\bar{w})}{\beta}-\kappa_d\right)-\kappa_d L^s\right)\Bigg] > 0\\
&\iff \ln(N_m)\bar{w}\ln(\bar{w})H^s\left(\frac{\ln(\bar{w})}{\beta}-\kappa_d+\frac{1}{\beta}\right)+\kappa_d L^s > H^s\left(\frac{\ln(\bar{w})}{\beta}-\kappa_d\right)
\end{aligned}$$

which holds since $\ln(N_m) > 1$ and $\ln(\bar{w})\left(\frac{\ln(\bar{w})}{\beta}-\kappa_d\right)+\frac{\ln(\bar{w})}{\beta} > \frac{\ln(\bar{w})}{\beta}-\kappa_d$. The first partial derivative of M_m with respect to $\frac{f_m}{f_d}$ given f_d is

$$\begin{aligned}
\frac{\partial M_m}{\partial\left(\frac{f_m}{f_d}\right)} &= \frac{1-\beta}{f_m^2(\kappa_m-\kappa_d)}\Bigg[f_m\left(\frac{d\bar{w}}{d\left(\frac{f_m}{f_d}\right)}H^s\left(\frac{\ln(\bar{w})}{\beta}-\kappa_d\right)+\frac{H^s}{\beta}\frac{d\bar{w}}{d\left(\frac{f_m}{f_d}\right)}\right)\\
&\quad -\left(\bar{w}H^S\left(\frac{\ln(\bar{w})}{\beta}-\kappa_d\right)-\kappa_d L^S\right)\Bigg] < 0
\end{aligned}$$

since $\frac{d\bar{w}}{d\left(\frac{f_m}{f_d}\right)} < 0$ from *Proposition 1.7* and $\bar{w}H^S\left(\frac{\ln(\bar{w})}{\beta}-\kappa_d\right)-\kappa_d L^S > 0$ if $M_m > 0$. Finally, the partial derivative of M_m with respect to κ_d is

$$\begin{aligned}
\frac{\partial M_m}{\partial \kappa_d} &= \frac{1-\beta}{f_m(\kappa_m-\kappa_d)^2}\Bigg[(\kappa_m-\kappa_d)\left(\frac{d\bar{w}}{d\kappa_d}H^s\left(\frac{\ln(\bar{w})}{\beta}-\kappa_d\right)+\frac{H^s}{\beta}\frac{d\bar{w}}{d\kappa_d}-\bar{w}H^s-L^s\right)\\
&\quad +\bar{w}H^S\left(\frac{\ln(\bar{w})}{\beta}-\kappa_d\right)-\kappa_d L^S\Bigg] < 0\\
&\iff \frac{H^s}{L^s} < \frac{\beta\kappa_m\left(1+\bar{w}\frac{H^s}{L^s}\right)}{\ln(\bar{w})\bar{w}}+\ln(N_d)\frac{H^s}{L^s}\Big(\ln(\bar{w})+1-\beta\kappa_d\Big).
\end{aligned}$$

Since $\ln(N_d) > 1$ and $\ln(\bar{w}) > \kappa_d$, it holds that $\frac{\partial M_m}{\partial \kappa_d} < 0$.

Proof of Proposition 1.8

Proof of $\forall \frac{f_m}{f_d} \leq \left(\frac{f_m}{f_d}\right)^*$, $M_m > 0$, $M_d = 0$:

Let me denote the largest $\frac{f_m}{f_d}$ that ensures $M_m > 0$, $M_d = 0$ by $\left(\frac{f_m}{f_d}\right)^*$. For any $\left(\frac{f_m}{f_d}\right)^*+\delta$,

$(\delta > 0)$ domestic firms enter and $M_m > 0$, $M_d > 0$. Thus $\forall \frac{f_m}{f_d} \leq \left(\frac{f_m}{f_d}\right)^*$,

$$M_d = \frac{(1-\beta)(\kappa_m L^S - \bar{w}H^S(\frac{\ln(\bar{w})}{\beta} - \kappa_m))}{f_d(\kappa_m - \kappa_d)} = 0 \iff \bar{w}H^s = \frac{\kappa_m L^s}{\frac{\ln \bar{w}}{\beta} - \kappa_m},$$

where the last equation determines the skill premium in an economy exclusively populated by κ_m-firms.

Proof of $\forall \frac{f_m}{f_d} \geq \left(\frac{f_m}{f_d}\right)^{**}$, $M_m = 0$, $M_d > 0$:

Let me denote the smallest $\frac{f_m}{f_d}$ that ensures $M_m = 0$, $M_d > 0$ by $\left(\frac{f_m}{f_d}\right)^{**}$. For any $\left(\frac{f_m}{f_d}\right)^{**} - \varepsilon$, $(\varepsilon > 0)$ MNEs enter and $M_m > 0$, $M_d > 0$. Thus $\forall \frac{f_m}{f_d} \geq \left(\frac{f_m}{f_d}\right)^{**}$,

$$M_m = \frac{(1-\beta)(\bar{w}H^S(\frac{\ln(\bar{w})}{\beta} - \kappa_d) - \kappa_d L^S)}{f_m(\kappa_m - \kappa_d)} = 0, \qquad \iff \bar{w}H^s = \frac{\kappa_d L^s}{\frac{\ln \bar{w}}{\beta} - \kappa_d},$$

where the last equation determines the skill premium in an economy exclusively populated by κ_d-firms.

Proof of $\left(\frac{f_m}{f_d}\right)^* < \left(\frac{f_m}{f_d}\right)^{**}$:

From *Lemma 1.3*, $\partial\phi_\Delta/\partial\bar{w} < 0$. Consequently, the right hand side of (1.29), $\frac{f_m}{f_d}$, can only be decreased if and only if the skill premium is increased. Thus, $\left(\frac{f_m}{f_d}\right)^* < \left(\frac{f_m}{f_d}\right)^{**} \iff \bar{w}^* > \bar{w}^{**}$. $M_m = 0$ implies a closed economy populated by κ_d-firms and $M_d = 0$ one by κ_m-firms. As *Proposition 1.4* states that $d\bar{w}/d\kappa > 0$, $\bar{w}^* > \bar{w}^{**}$ and consequently $\left(\frac{f_m}{f_d}\right)^* < \left(\frac{f_m}{f_d}\right)^{**}$. This implies the existence of the interval $\left(\left(\frac{f_m}{f_d}\right)^*, \left(\frac{f_m}{f_d}\right)^{**}\right)$.

Proof of $\left(\frac{f_m}{f_d}\right)^*$ is increasing in κ_m:

According to *Lemma 1.5*, M_d decreases in κ_m. Holding all other parameters constant, increasing κ_m from κ_m^0 to κ_m^1 implies that $\exists \frac{f_m}{f_d} > \left(\frac{f_m}{f_d}\right)^* (\kappa_m^0)$ that ensure $M_d = 0$. The largest of those $\frac{f_m}{f_d}$'s is $\left(\frac{f_m}{f_d}\right)^* (\kappa_m^1) > \left(\frac{f_m}{f_d}\right)^* (\kappa_m^0)$.

Proof of $\left(\frac{f_m}{f_d}\right)^{**}$ is decreasing in κ_d:

According to *Lemma 1.5*, M_m decreases in κ_d. Holding all other parameters constant, increasing κ_d from κ_d^0 to κ_d^1 implies that $\exists \frac{f_m}{f_d} < \left(\frac{f_m}{f_d}\right)^{**} (\kappa_d^0)$ that ensure $M_m = 0$. The smallest of those $\frac{f_m}{f_d}$'s is $\left(\frac{f_m}{f_d}\right)^{**} (\kappa_d^1) < \left(\frac{f_m}{f_d}\right)^{**} (\kappa_d^0)$.

Proof of Proposition 1.6

Since $\kappa_m > \kappa_d$ and $dN/d\kappa > 0$, it always holds that $N_{o,m} > N_{o,d}$ and, thus, $N_{o,m} \leq \mu \Rightarrow N_{o,d} \leq \mu$. $N_{o,m} \leq \mu$ is left to proof. Furthermore, $dN/d\bar{w} < 0$ and, consequently, $N_{o,m}$ is greatest in an economy with the lowest $\bar{w}$ which is an economy populated exclusively by domestic firms. Similar to the proof of $N_{c,d} \leq \mu$ in *Appendix 1.7.7*, the optimal technology choice of MNEs is approximated by a Taylor expansion where I set $N_{o,m} \leq \mu$. This is plugged into the skill premium equation of an autarkic economy, (1.21), which results in the threshold that ensures $N_{o,m} \leq \mu$:

$$\frac{H^s}{L^s} \leq \exp\left(\frac{-2\kappa_m}{1-\kappa_m\sigma}\right)\frac{1-\kappa_m\sigma}{\frac{2}{\beta}\frac{\kappa_m}{\kappa_d} - 1 + \kappa_m\sigma}.$$

Chapter 2

Do All Firms Profit from Lower Barriers to Technology Adoption?

2.1 Introduction

The majority of the economic literature agrees that roughly 50 % of differences in output per worker across countries can be accounted for disparities in total factor productivity (TFP)[1]. Moreover, being a general mapping from aggregate factors to aggregate output, TFP represents in essence a country's production technique (Gancia et al., 2011). The observation that countries differ largely in their use of technology in the production process is usually attributed to two major sources. First, the appropriate technology literature[2] emphasizes the importance of differences in country-level skill endowments. Second, an amplitude of differing barriers to technology adoption prevent the implementation of the most efficient production techniques[3]. The study of Caselli and Coleman (2006) unites the two strands of the literature and shows that half of cross-country disparities in income stem from restrictions on the use of appropriate technologies. Like other studies, they concentrate on the barrier's impact on the country-level although, from a disaggregated perspective, a country's firms have to cope with restrictions on technology choices (Parente

[1]E.g. Hall and Jones (1999) claim a greater impact of TFP whereas Caselli and Coleman (2006) report a share of 40%.

[2]Acemoglu and Zilibotti (2001) claim that techniques developped in skill-rich countries cannot be adopted efficiently in skill-scarce countries.

[3]See *Section 2.2 for a literature review on barriers to technology adoption.*

and Prescott, 2002). While various studies show that the heterogeneity of firms[4] has far-reaching economic implications, the impact of barriers on firms' technology choices may well be of an asymmetric nature. In other words, firms from low-productivity industries anticipate their technological disadvantage vis-à-vis more productive firms and lobby for the maintenance and/or erection of barriers to protect their vested interests. However, there exists to the best of my knowledge no study that analyzes the impact of lower barriers to technology adoption on the difference in endogenous technology choices between more and less productive firms.

My model is the first to formalize the intuition that lower barriers to technology adoption increase the technology gap between high- and low-productivity firms. Moreover, I show that while the gap in technology choices widens, a country's overall level of welfare increases where the latter effect constitutes a well-known fact (Caselli and Coleman, 2006; Gancia et al., 2011).

In my theoretical analysis, more and less productive firms choose endogenously their production techniques. They differ with respect to the scope for technology in production, i.e. high-productivity firms (h-firms) are endowed with an inherent advantage such that their use of technology in the production process is more efficient than that of low-productivity firms (l-firms). However, the former have to incur higher market entry costs since a higher level of efficiency usually involves greater investments in research and development. Moreover, l-firms reduce their technological disadvantage and protect their vested interests by urging policy makers to impose barriers to technology adoption. In this way, h-firms are precluded from the use of their optimal technology level (Parente and Prescott, 2002). Although studying the underlying causes of barriers may be of interest in itself, it is behind the scope of this study and constitutes no prerequisite for my analysis of differential impacts of lower barriers on heterogeneous firms. Similar to my approach in the first chapter of this dissertation, the adoption of more sophisticated technologies requires a more skilled workforce, i.e. technology is complementary to high-skilled labor (Goldin and Katz, 1998). However, the implied increase in skill-intensity raises a firm's labor

[4]See e.g. Bernard and Jensen (1995, 1999) and Bernard et al. (2007) for heterogeneity with respect to productivity. Furthermore, Bustos (2011) models and estimates heterogeneous levels of technology in production.

costs since more qualified workers earn a skill premium over less skilled.

When e.g. vested interest groups lose political influence and barriers to technology adoption are decreased, high-productivity firms will adopt more sophisticated production techniques. Along with the involved rise in productivity, h-firms increase their relative demand of high-skilled workers which, in turn, leads to a rise in the wage gap. The pre-reform technology level of low-productivity firms becomes more expensive, causing them to downgrade their production techniques. As a consequence, the technology gap of h- to l-firms increases, highlighting the motivation of low-productivity firms to lobby against lower barriers in the first place. Although a decrease in barriers to technology adoption has opposing impacts on h- and l-firms, it unambiguously increases a country's overall welfare which is in line with the literature (Caselli and Coleman, 2006; Gancia et al., 2011).

In this study, barriers to technology adoption are exogenous and of a rather abstract nature in order to accommodate a variety of different causes. Nevertheless, there exists an extensive literature on the origins of barriers to technology adoption and their effects on a country's output per worker, skill premium, technologies, and welfare which is discussed in more detail in *Section 2.2.* Parente and Prescott (2002), Caselli and Coleman (2006), Gancia et al. (2011), and others[5] show that removing barriers to technology adoption would lead to a massive increase in per capita income of developing countries. While having a different focus my model replicates this 'stylized fact'. Similar to a recent study by Gancia et al. (2011), I show that lower barriers imply an increase in the skill premium which in my model widens the technology gap between h- and l-firms. Since lower barriers usually involve a greater openness, this relates to the literature on the effects of globalization on the wage gap in developing countries (Goldberg and Pavcnik, 2007).

Empirical evidence on the impact of lower barriers to technology adoption on the technology gap between different types of firms is relatively scarce. In a recent study, Bustos (2011) analyzes the impact of reducing Brazilian tariffs against Argentinian firms on the endogenous technology choices of firms in Argentina. She shows that most productive firms within an Argentinian industry increase their level of technology the most. Ozler and Yilmaz (2009) analyze productivity improvements caused by declining protection

[5] E.g. Hall and Jones (1999), Klenow and Rodríguez-Clare (2005), Harding and Rattso (2005).

rates in trade policy and conclude that larger firms (which are usually more productive) benefit more. Nakamura and Ohashi (2008)'s study of the Japanese steel industry in the 1950's and 60's shows that more productive firms were more inclined to adopt newly available technologies.

This chapter of my dissertation contributes to an emerging theoretical literature. In Parente and Prescott (1994, 2002), barriers to technology adoption are explicitly modeled as an increase in investment costs that incur to improve a plant's quality or to enhance a firm's physical capital. In a second step, they aggregate firm-level decisions such that barriers to plant-level efficiency can be related to cross-country TFP differences. However, their assumption of homogeneous firms abstracts from any differential impact of lower barriers on technology levels of firms. Moreover, the assumption of homogeneous labor supply ignores the impact of lower barriers on the skill premium. In contrast, Caselli and Coleman (2006) build a model with an aggregated production function and heterogeneous labor where lower barriers to technology adoption increase the skill premium and, simultaneously, output per worker[6]. Their analysis links the literature on barriers to technology adoption to studies on country-appropriate technologies[7]. In a recent contribution, Gancia et al. (2011) incorporate Caselli and Coleman (2006)'s approach into a North-South model that endogenizes barriers to technology adoption. In the empirical part of their study, a reduction in barriers implies a rise both in the skill premium and in the adoption of skill-biased technologies. However, in both studies output is produced according to a country-level production function that neglects firm-level decisions as well as differences in technology choices across firms.

I am the first to analyze the impact of lower barriers to technology adoption on firm-level differences in optimal production techniques. My model shows that while the technology gap between more and less productive firms rises, a country's skill premium increases and its overall welfare-level improves.

This chapter of my dissertation is structured as follows. *Section 2.2* briefly presents

[6]Growth of per capita income constitutes the focus of endogenous growth models. E.g., Barro and Sala-i Martin (1997) incorporate explicit costs of technology adoption and Howitt (2000) accounts for the impact of regulatory policies on the extend of technology transfers in explaining cross-country differences in productivities.

[7]See e.g. Acemoglu and Zilibotti (2001) where the better a technology fits a country's skill endowment the more efficient it is.

evidence on barriers to technology adoption. *Section 2.3* analyzes firm-level decisions on the level of technology in production and studies the impact of lower barriers to technology adoption given wages. In *Section 2.4*, homogeneous firms' behavior is embedded in a general equilibrium framework and the impact of lower barriers on the skill premium and aggregated welfare is analyzed. *Section 2.5* introduces the heterogeneous firms equilibrium and studies the consequences of lower barriers to technology adoption with a focus on the technology gap between more and less productive firms, the skill premium, and overall welfare. *Section 2.6* briefly concludes.

2.2 Sources and Consequences of Barriers to Technology Adoption

Throughout this chapter, barriers to technology adoption are summarized into an abstract and simple measure that is exogenously given. Nevertheless, there exists a vast array of empirical and anecdotal evidence on the political, institutional, and historical causes and forms of barriers to technology adoption. In a seminal work, Parente and Prescott (2002) motivate a model of micro-founded barriers by providing an extensive literature overview of different institutional causes and forms. First, their approach of modeling barriers as restrictions to plant-level investments is influenced by de Soto (1989)'s cross-country comparisons of regulatory constraints to set up new firms. In particular, the latter process can take more than 250 working days and demands bribery in Peru while in New York City, it requires only 2 hours and no briberies to be made[8]. Second, Parente and Prescott (2002) provide historical evidence, e.g. Wolcott (1994)'s study on the productivity growth of Japanese and Indian textile industries from 1920 to 1938. Whereas Indian textile workers received extensive governmental support to prevent the introduction of labor-saving machinery, their Japanese counterpart did not, leading to a much higher productivity growth in Japan (120%) than in India (40%). Parente and Prescott (2002) present another historical example where governmental non-acting eroded barriers to tech-

[8]In Parente and Prescott (2005), they bolster the hypothesis of widespread political constraints that restrict firms' decisions on technology and productivity by Djankov et al. (2002)'s cross-country comparisons of legal requirements to set up a new firm.

nology adoption: upheavals in the English woolen industry at the end of the eighteenth and beginning of the nineteenth century. According to Randall (1991), fierce resistance of shearers against the introduction of gig mills, which resulted in hugh labor-savings in the examination and repair of finished cloth, failed as its use was not forbidden by the government. Nevertheless, the shearers managed to resist the application of gig mills in some regions for nearly 25 years and had to capitulate in particular due to increasing competition from regions where gig mills were already prevalent. Third, Baily (1993) and Baily and Gersbach (1995) present cross-country comparisons of technology use in service and manufacturing industries. Plants of multinational corporations located in different countries have usually access to the same base of knowledge, but use in fact different amounts of knowledge and apply different work practices. For instance, Ford U.S.A. has adopted Japanese just-in-time production while Ford Europe failed to do so. Another example is the beer industry, where much of the high technology machinery used in Japanese and U.S. plants is manufactured in Germany. However, German breweries fail to use these more productive technologies as explicit rules and regulations govern German beer production. Furthermore, a smaller productivity of the European vis-à-vis the American airline sector is the result of overstaffing which cannot be reduced because of union rules and political opposition. Parente and Prescott (2002)'s conclusion from Baily (1993) and Baily and Gersbach (1995) is that cross-country differences in production technologies can be explained by explicit constraints that prevent changes in work practices and the use of better technologies.

In a similar vein, Acemoglu and Robinson (2000) focus on the nature of political institutions to analyze technological backwardness across countries. They motivate their model on political losers that erect barriers to technology advances to protect their political power by a variety of historical evidence. In particular, Mokyr (1990) contrasts the Luddites, skilled weavers that faced unemployment from technological progress, and the land-owning elites in the 19th century. Whereas the former attempted but ultimately failed to halt advances in mechanization, the latter did not stop the evolution since their continued political power was secure. This was different in Russia where the elites opposed economic advances, fearing social and political change, and admitted it only after having been defeated heavily in the Crimean War (Mosse, 1992).

In a different approach, Comin et al. (2008) show that there exist large cross-country time lags in the use of technologies which account for substantive TFP differences. Spolaore and Wacziarg (2011) demonstrate that the implied cross-country differences in technology adoption stem from massive barriers to technology adoption. The latter are caused by the degree of long-term historical relatedness between human populations since societies that share more cultural and other traits are more likely to adopt technologies from each other. In particular, the relative frontier distance, defined by Spolaore and Wacziarg (2011) as the relatedness of a country's population to that of the U.S., explains large differences in the adoption of technologies.

Although the above empirical study focuses on rigid barriers to technology adoption, most other economists agree on the fact that barriers are mainly shaped by modifiable regulations and institutions. Ngai (2004) shows that changes in institutions which imply changes in barriers to technology adoption have far reaching economic consequences. In her article on long-term economic growth, higher barriers not only lower the level of income along a balanced growth path, but also delay an economy's turning point from extensive, i.e. traditional, to modern economic growth. The latter happened in Argentina where changes in institutions implied a rise in barriers to technology adoption. In contrast, institutions in Japan improved such that barriers decreased, involving a higher income level along its balanced growth path and an earlier start of modern economic growth. Moreover, Hall and Jones (1999) explain cross-country differences in output per worker by differences in institutions and government policies. Those favorable to high levels of output per worker provide an environment that supports among others technology transfers, i.e. low barriers to technology adoption. Klenow and Rodríguez-Clare (2005) show that modest barriers to international knowledge spillovers could hinder international technology diffusion and account for great differences in TFP. Harding and Rattso (2005) establish a long run relationship between South African productivity and the world technology frontier where changes in the barrier to technology adoption affect transitional growth.

2.3 Firm-Level Analysis

Since more and less productive firms differ exclusively with respect to their scope of technology in production, their production possibilities and respective optimal choices given market size (A) and wages (w_H, w_L) do not require a distinct analysis. Market size and wages will be endogenously determined in general equilibrium analysis.

2.3.1 Production

Each firm i produces output Y_i according to the production function

$$Y_i := N_i^{\kappa_i+1}\left(\frac{1}{N_i}\int_0^{N_i} x_{i,j}^{\frac{\sigma}{1+\sigma}}\,dj\right)^{\frac{1+\sigma}{\sigma}} \tag{2.1}$$

where N_i denotes the level of technology in production and $x_{i,j}$ the respective input quantity of each intermediate input. In particular, a firm chooses a subset $[0, N_i]$ out of the available set of intermediate inputs $[0,T] \subseteq [0,\mu]$ with $1 \ll T \leq \mu$[9]. T is an inverse measure of barriers to technology adoption that summarizes the constraints a firm faces in its decision on the optimal level of technology in production. The smaller T, the less sophisticated are the production techniques a firm may adopt. The barrier to technology adoption binds and the firm is technologically constrained if $N_i^* > T$ where N_i^* represents the optimal choice of technology in the absence of barriers. In the following, N_i denotes a firm's level of technology which will be replaced by N_i^* or, respectively, by T if clarification is required.

A firm's technology type $\kappa_i > 0$ captures the extent to which a firm benefits from technology, i.e. by how much technology augments a firm's output. Whenever there is no loss of clarification, I will abstract from the firm index i to save on notation. Furthermore, $\sigma \in (0,\infty)$ determines the elasticity of substitution between different intermediate inputs in production, $1+\sigma > 1$. Also, I impose $\kappa\sigma < 1$[10].

[9]Note that the assumption of an overall upper limit to technology, $0 \ll \mu < \infty$, constitutes a modeling necessity to ensure that Cobb-Douglas exponents in the production function of intermediate inputs (1.2) are in $[0,1]$.

[10]This implies a defined choice of N. See the first chapter for further details.

Each intermediate input $j \in [0, N]$ is produced according to

$$x_j(L_j, H_j) := z_j L_j^{1-\frac{j}{\mu}} H_j^{\frac{j}{\mu}} \tag{2.2}$$

where $z_j = \left(\frac{j}{\mu}\right)^{-\frac{j}{\mu}} (1-\frac{j}{\mu})^{-(1-\frac{j}{\mu})}$, H_j is the input quantity of high- and L_j that of low-skilled labor. Total employment of each skill category within a firm is given by $L \equiv \int_0^N L_j dj$ and $H \equiv \int_0^N H_j dj$. In essence, (2.2) constitutes a smooth way of modeling technology-skill complementarity. See the first chapter for more details. Minimum unit costs of producing one unit of j are

$$k_j = w_L \bar{w}^{\frac{j}{\mu}} \tag{2.3}$$

where $\bar{w} \equiv \frac{w_H}{w_L}$ is defined as the wage gap between high- and low-skilled labor.

2.3.2 Profit Maximization

A firm's profit reads as

$$\Pi\left(N, \{L_j\}_0^N, \{H_j\}_0^N\right) = A^{1-\beta} Y^\beta - C(Y) = A^{1-\beta} Y(H, L)^\beta - \int_0^N [w_H H_j + w_L L_j]\, dj,$$

where $A^{1-\beta} Y^\beta = pY$ is a firm's revenue (derived from household's demand (1.17)), β determines the elasticity of demand $1/(1-\beta)$, and $C(Y)$ are the (labor) costs of producing Y. Profit maximization implies to choose the optimal quantities of H_j and L_j $\forall j \in [0, N]$, weigh them with respective wages, and aggregate to obtain a firm's cost.

A different approach consists in using the minimum unit cost function k_j. Then, the firm's problem becomes

$$\max_{N, \{x_j\}_0^N} \Pi\left(N, \{x_j\}_0^N\right) = \max_{N, \{x_j\}_0^N} \left\{A^{1-\beta} Y(N, \{x_j\}_0^N)^\beta - \int_0^N k_j x_j dj\right\} \tag{2.4}$$

and the number of endogenous variables is reduced from $2N + 1$ to $N + 1$. I further impose that $N > 0$ to ensure a positive demand of high-skilled labor (see (2.2)). In general equilibrium, wages adjust such that $N = 0$ would never constitute an optimal choice. Moreover, each firm is constrained to choose a level of technology in production that does not exceed the barrier to technology adoption. As a consequence, each firm has to maximize its profit for $N \in (0, T]$.

2.3.3 Optimal Firm Behavior

A firm's optimal production structure given wages and market size depends on the profit-maximizing level of technology as well as on the optimal quantities of intermediates in production. The latter relate through the production function of intermediates to the corresponding optimal demands of high- and low-skilled labor. For this and the following section, I impose $e^{\kappa\mu} > \bar{w} > e^{\frac{2\kappa}{1-\kappa\sigma}}$ to ensure an optimal choice of technology within $(1, \mu]$. As $e^{\frac{2\kappa}{1-\kappa\sigma}} > e^{\kappa\beta}$, $\bar{w} > e^{\frac{2\kappa}{1-\kappa\sigma}}$ also ensures positive high- and low-skilled labor demands.

The first order maximization conditions derived from (2.4) determine the optimal quantity of intermediate input $j \in [0, N]$ for any level of technology $N \in (0, T]$,

$$x_j = \beta^{\frac{1}{1-\beta}} A N^{\frac{\beta(\kappa+1)-1}{1-\beta}} \bar{K}_N^{\sigma-\frac{\beta}{1-\beta}} k_j^{-1-\sigma}, \tag{2.5}$$

where $\bar{K}_N \equiv \left[\frac{1}{N}\int_0^N k_j^{-\sigma} dj\right]^{-\frac{1}{\sigma}}$ are average minimal unit costs. A derivation of first order conditions is given in *Appendix 2.7.1* which also shows that the exclusive impact of barriers to technology adoption on the optimal quantity of x_j given in (2.5) consists in the level of technology in production. Whenever the latter is chosen optimally, the respective level of technology is determined by the first order condition $\frac{\partial \Pi}{\partial N} = 0$. However, as long as

$$\frac{\partial \Pi}{\partial N} = \frac{\Pi}{N}\left(\kappa - \underbrace{\left(N\frac{\partial \bar{K}_N}{\partial N}\right)/\bar{K}_N}_{\equiv \varepsilon_{\bar{K}_N}}\right) > 0,$$

barriers to technology adoption (T) restrict a firms choice and $N^* > T$. $\varepsilon_{\bar{K}_N}$ is defined as the elasticity of $\bar{K}_N$ with respect to N where $\partial\varepsilon_{\bar{K}_N}/\partial N > 0$ (see *Appendix 2.7.2*). As a consequence, whenever a firm's endogenous technology choice is constrained by the barrier, it is optimal to adopt the most sophisticated production technique that is available: T. In contrast, if $\frac{\partial \Pi}{\partial N} = 0$ which implies $\kappa = \varepsilon_{\bar{K}_{N^*}}$ given intermediates' production function (2.2), a firm is able to implement its optimal technology level, $N^* \leq T$.

Using minimal unit costs (2.3) derived from the adjusted Cobb-Douglas production function for intermediate inputs, the index of average unit costs can be rewritten as $\bar{K}_N = w_L \left(\frac{1}{N} \int_0^N \bar{w}^{-\sigma \frac{j}{\mu}} dj \right)^{-\frac{1}{\sigma}} = w_L \left(\frac{\bar{w}^{-\sigma \frac{N}{\mu}} - 1}{\frac{N}{\mu}(-\sigma) \ln \bar{w}} \right)^{-\frac{1}{\sigma}}$. This implies the following elasticity of average unit costs[11] with respect to the level of technology N:

$$\varepsilon_{\bar{K}_N} = \frac{1}{\sigma} - \frac{\frac{N}{\mu} \ln \bar{w}}{\bar{w}^{\sigma \frac{N}{\mu}} - 1}. \tag{2.6}$$

If barriers to technology adoption do not restrict a firm's technology choice, (2.6) equals a firm's scope for technology in production, κ, and determines in this way the optimal technology level N^*. For the unrestricted case, the proof of uniqueness of a firm's endogenous level of technology is given in the first chapter. Moreover, if the barrier constrains the technology adoption decision, a firm will always choose the highest attainable level since $\frac{\partial \Pi}{\partial N} > 0$ for $N^* > T$. As a consequence, a firm's choice of the level of technology in production is unique in either case, i.e. regardless whether $N^* \gtreqless T$.

Optimal output of the firm depends directly and indirectly on the level of technology in production,

$$Y = \beta^{\frac{1}{1-\beta}} A N^{\frac{\kappa}{1-\beta}} \bar{K}_N^{-\frac{1}{1-\beta}}, \tag{2.7}$$

since the technology-skill complementarity implies that $\bar{K}_N$ increases in N, i.e. $\varepsilon_{\bar{K}_N} > 0$. Prices are derived from firm-level output (2.7) and the representative household's demand, $Y = Ap^{\frac{1}{\beta - 1}}$. As in a standard Dixit-Stiglitz economy, they are set as a mark-up over marginal costs:

$$p = \frac{\bar{K}_N}{N^\kappa \beta}. \tag{2.8}$$

Total production costs are given by $C(Y) = w_H H + w_L L$ and become, evaluated at the optimum, $\frac{Y \bar{K}_N}{N^\kappa}$. Note that $C(Y)$ are nominal and real costs as real wages are given by $\frac{w_H}{P_I}$ and $\frac{w_L}{P_I}$, respectively, where P_I represents the price index which is normalized to one in general equilibrium[12]. Hence, productivity is defined as real output over real production costs:

$$\phi \equiv \frac{Y}{C(Y)} = \frac{N^\kappa}{\bar{K}_N} = \frac{N^\kappa}{w_L \bar{w}^{\frac{N}{\mu}} \left(1 - \sigma \varepsilon_{\bar{K}_N}\right)^{\frac{1}{\sigma}}}. \tag{2.9}$$

[11] Remark that $\bar{K}_N = w_L \bar{w}^{\frac{N}{\mu}} \left(\sigma \frac{\frac{N}{\mu} \ln \bar{w}}{\bar{w}^{\sigma \frac{N}{\mu}} - 1} \right)^{\frac{1}{\sigma}} = w_L \bar{w}^{\frac{N}{\mu}} \left(1 - \sigma \varepsilon_{\bar{K}_N}\right)^{\frac{1}{\sigma}}$.

[12] P_I could be included as a constant in the function of productivity but this would not alter any result.

Therefore, firm-level productivity depends on the skill premium and the level of technology but, beyond that, also on the wage level (i.e. it takes into account the level of production costs). Furthermore, a final good's price relates proportionally to productivity, $p = \frac{1}{\phi\beta}$, whereby both represent equivalent measures of efficiency.

Foreshadowing the heterogeneous firms equilibrium, I assume in the following two different types of firms where the high-productivity firm (h-firm) has a greater scope for technology in production, κ_h, than the low-productivity firm (l-firm), κ_l, i.e. $\kappa_h > \kappa_l$. While their technology gap is defined as $\frac{N_h}{N_l}$, their difference in productivities is given by

$$\phi_\Delta \equiv \frac{\phi_h}{\phi_l} = \frac{N_h^{\kappa_h}}{N_l^{\kappa_l}} \bar{w}^{-\frac{N_h - N_l}{\mu}} \left(\frac{1 - \sigma \varepsilon_{\bar{K}_{N_l}}}{1 - \sigma \varepsilon_{\bar{K}_{N_h}}} \right)^{\frac{1}{\sigma}} \tag{2.10}$$

which immediately follows from (2.9). Note that in contrast to productivity levels the productivity gap ϕ_Δ is independent of wage levels but depends on the respective technology levels of more and less productive firms as well as on the the skill premium. Since I will impose in the heterogeneous firms case that h-firms are constrained while l-firms are not, high-productivity firms' technology choice will be restricted to T whereas N_l will be chosen endogenously by l-firms through the first order condition $\kappa_l = \varepsilon_{\bar{K}_{N_l}}$. In this case, productivity differences will become $\phi_\Delta = \frac{T^{\kappa_h}}{N_l^{\kappa_l}} \bar{w}^{-\frac{T - N_l}{\mu}} \left(\frac{1 - \sigma \kappa_l}{1 - \sigma \varepsilon_{\bar{K}_T}} \right)^{\frac{1}{\sigma}}$ and will depend directly and indirectly (through $\varepsilon_{\bar{K}_T}$) on barriers to technology adoption.

Labor is the only factor in the production of intermediate inputs. In particular, labor resources devoted to intermediates' production are labeled production labor to distinguish them from resources required for market entry. Respective production labor demands for each intermediate input as well as aggregated demands on the firm-level are derived in *Appendix 2.7.3.* A firm's factor demands of high- and low-skilled labor can be summarized as

$$H = \beta p Y \frac{\varepsilon_{\bar{K}_N}}{w_H \ln \bar{w}}, \tag{2.11}$$

$$L = \beta p Y \frac{\ln \bar{w} - \varepsilon_{\bar{K}_N}}{w_L \ln \bar{w}}. \tag{2.12}$$

Note that if a firm is constrained by the barrier to technology adoption, $\varepsilon_{\bar{K}_N} = \varepsilon_{\bar{K}_T}$, and, in the case of an endogenous choice of the optimal level of technology in production, $\varepsilon_{\bar{K}_N} = \kappa$. This implies that relative high- to low-skilled production labor demands

$$\frac{H}{L} = \frac{1}{\bar{w}} \frac{\varepsilon_{\bar{K}_N}}{\ln \bar{w} - \varepsilon_{\bar{K}_N}}. \tag{2.13}$$

depend on the level of technology in the case of high-productivity firms since $N_h = T$. In contrast, low-productivity firms' relative high- to low-skilled production labor demands are independent of their level of technology N_l. However, low-productivity firms' production techniques and relative high- to low-skilled production labor demands are given by their common determinants κ_l and the skill premium.

2.3.4 Firm-Level Impacts of Changes in Skill Premia and Barriers to Technology Adoption

From a firm's perspective, the skill premium is exogenous akin to the barrier to technology adoption. Moreover, a respective increase or decrease has an impact on the firm's technology choice and the resulting productivity level whenever the wage gap or the barrier constitutes a determining factor in the decision process. This implies that a lower skill premium affects the optimal technology choice if and only if the barrier does not bind. Vice versa, a lower barrier has an impact on the adoption of production techniques if and only if the endogenous choice of the level of technology is constrained by the barrier.

Proposition 2.1 *Assume that firms' choices of the level of technology in production are not restricted by the barrier. Then, the technology level decreases in the skill premium,* $\frac{dN^*}{d\bar{w}} = -\frac{N^*}{\bar{w}\ln\bar{w}} < 0$*, and increases in a firm's technology type,* $\frac{dN^*}{d\kappa} = \frac{N^*}{(1-\kappa\sigma)\left(\frac{N^*}{\mu}\ln\bar{w}-\kappa\right)} > 0$*. Furthermore, productivity increases in the technology type,* $\frac{\partial\phi}{\partial\kappa} = \ln(N^*)\phi > 0$*, decreases in the wage gap,* $\frac{\partial\phi}{\partial\bar{w}} = -\frac{\kappa\phi}{\bar{w}\ln\bar{w}} < 0$*, and the productivity gap shrinks in the skill premium,* $\frac{\partial\phi_\Delta}{\partial\bar{w}} = -\phi_\Delta\frac{\kappa_h-\kappa_d}{\bar{w}\ln\bar{w}} < 0$.

The case where the barrier to technology adoption has no impact on the production process applies in particular to low-productivity firms when wages are exogenous. Their level of skill-complementary technology in production is downgraded if its implicit price, the skill premium, increases. As a result, l-firms' productivity is dampened. Since a greater scope for technology in production implies a more productive use of technology, an increase in κ leads to a choice of more sophisticated production techniques and a higher productivity. Consequently, a graduate increase in barriers to technology adoption will restrict higher κ (high-productivity) firms first. Moreover, given that neither type is constrained, h-firms have to downgrade their production techniques by more than l-firms when the skill premium increases since the latter has a stronger impact on more technology intensive production processes[13].

In contrast to the above analysis, assume that a high-productivity firm's choice is restricted by the barrier. Then, the adoption of higher technology levels when the wage gap shrinks is not feasible. Remark that I abstract in the following from very sharp skill premium increases which may induce high-productivity firms to choose optimal technology levels below the barrier, i.e. $N^* < T$. Whether $N^* > T$ decreases to $N^{**} \gtreqless T$, where $N^* > N^{**}$, is in fact determined by firm-level parameters κ and σ in combination with the extend of the skill premium rise and the level of the barrier. For example, if high-productivity firms are endowed with a relatively small scope for technology in production, their choice of technology would be more prone to a decrease as a result of a sharp rise in the wage gap. However, considering cases where $N^* > T$ is dampened to $N^{**} < T$ would not add insights to the present analysis.

Proposition 2.2 *Given wages, a firm's choice of technology is constrained if and only if* $T < \frac{2\kappa\mu}{\ln(\bar{w})(1-\kappa\sigma)}$. *Moreover, high-productivity firms are constrained while low-productivity firms are not if and only if* $\kappa_l < \frac{1}{\frac{2\mu}{\ln(\bar{w})T}+\sigma} < \kappa_h$.

The proof is given in Appendix 2.7.4. Lower skill premia involve lower adoption costs and increase a firm's optimal technology level which is then obviously more likely to be constrained. Furthermore, firms that are endowed with a greater κ usually choose higher levels of technology in production, and are consequently more prone to become constrained by the barrier. The more restrictive the latter is (i.e., the smaller T) the more likely it constrains firms' production techniques. Since the skill premium represents the implicit costs of technology in production, a lower wage gap decreases technology adoption costs

[13]See the first chapter for proofs as well as an detailed discussion of the unconstrained cases.

and makes firms more prone to become technologically constrained. To sum up, a relative restrictive barrier constrains a firm's choice if it has a great scope for technology and faces a rather low skill premium.

In essence, the difference in their respective scopes for technology in production implies whether high-productivity firms are restricted in their endogenous choice of technology while low-productivity firms are not. Remark that $\kappa_h > \kappa_l$ is not sufficient but that h-firms' technology type has to be greater than a threshold while l-firms' scope for technology has to be smaller. Moreover, this requires rather medium levels of the skill premium and the barrier to technology adoption. Note that in comparison to the case where both are unrestricted the technology gap is smaller if barriers constrain high-productivity but not low-productivity firms' choices.

Proposition 2.3 *If a firm's choice of technology in production is constrained by the barrier, productivity increases when the barrier is lowered (i.e. T increases), $\frac{\partial \phi}{\partial T} = \phi \frac{\kappa - \varepsilon_{\bar{K}_T}}{T} > 0$, and decreases when the skill premium rises, $\frac{\partial \phi}{\partial \bar{w}} = -\frac{\varepsilon_{\bar{K}_T} \phi}{\bar{w} \ln \bar{w}} < 0$. Furthermore, relative production labor demands increase if the barrier is reduced.*

Assume that high-productivity firms' technology choices are restricted while low-productivity firms' are not. Then, ϕ_Δ increases when the barrier is lowered, $\frac{\partial \phi_\Delta}{\partial T} = \phi_\Delta \frac{\kappa_h - \varepsilon_{\bar{K}_T}}{T} > 0$, and decreases for higher skill premia, $\frac{\partial \phi_\Delta}{\partial \bar{w}} = -\phi_\Delta \frac{\varepsilon_{\bar{K}_T} - \kappa_l}{\bar{w} \ln \bar{w}} < 0$.

The proof is given in Appendix 2.7.4. Given that barriers to technology adoption indeed restrict a firm's choice the latter is confined to produce with less sophisticated technologies. Since higher levels of technology augment production a firm's productivity is necessarily dampened. A reform in policies and institutions that involves lower barriers implies the adoption of more productive technologies. Note that the increase in productivity is proportional to the difference $\kappa - \varepsilon_{\bar{K}_T}$. The closer T is to N^* the smaller is the marginal gain from a rise in T since the cost elasticity of technology adoption ($\varepsilon_{\bar{K}_N}$) increases in the level of technology and dampens the positive effect of technology on productivity. If $\kappa = \varepsilon_{\bar{K}_T}$ barriers do not impede an optimal choice of technology and the marginal gain of lower barriers vanishes.

Similar to the case of unrestricted choices a higher wag gap rises the cost of technology and implies lower levels of technology in production and, consequently, a lower productivity. However, the downgrade is somewhat dampened by the factor $\varepsilon_{\bar{K}_T} < \kappa$ as the lower technology level in the constrained case requires relatively less high-skilled labor. In a similar vein, lower barriers imply more sophisticated production techniques that require relatively more high-skilled workers.

In the case of heterogeneous firms, high-productivity firms' use of technology in production is more efficient than low-productivity firms' whereas the former's optimal technology choice is constrained in contrast to the latter's. In particular, this case emerges when low-productivity firms manage to influence politics to protect their vested interests. Resulting e.g. from a reform in regulations, lower barriers to technology adoption enable h-firms to use more sophisticated production techniques and increase their productivity while having no impact on l-firms when wages are exogenous. As an immediate result, the productivity gap rises proportionally to $\kappa_h - \varepsilon_{\bar{K}_T}$. That is, akin to $\frac{\partial \phi}{\partial T}$, increases in the productivity gap abate if T approaches high-productivity firms' optimal technology level.

On the other hand, h-firms have to employ relatively more high-skilled labor due to the complementarity of technology and skills. They will suffer more in terms of productivity from a skill premium increase. The relative loss is again proportional to $\varepsilon_{\bar{K}_T} - \kappa_l$ and, thus, smaller than in the unconstrained case as restricted h-firms employ relatively less high-skilled labor than they would in optimum.

2.4 Homogeneous Firms Equilibrium

A firm's level of technology in production and the related demands of high- and low-skilled labor are embedded in a Dixit-Stiglitz economy. In this section, I will abstract from any differences across firms and will focus on the equilibrium impact of barriers to technology adoption on firm-level and aggregated variables. In a first step, firms are assumed to be constrained in their technology choice by the barrier to technology adoption. The resulting wage levels and the skill premium are determined. In a second step, I analyze under which conditions firms' technology levels are restricted by the barrier. Lowering the latter has various implications for wages and welfare which are explored subsequently in detail.

The representative household has a CES-utility function

$$u = \left(\int_0^M Y_i^\beta di \right)^{\frac{1}{\beta}}, \quad 0 < \beta < 1,$$

and supplies low- and high-skilled labor (L^s, H^s) inelastically. There exists a continuum of final goods Y_i, with $i \in [0, M]$, that are produced by a homogeneous mass M of firms that are all of technology type κ. The elasticity of substitution between final goods is $\frac{1}{1-\beta} > 1$. The above taste for variety preferences imply the demand function

$$Y_i = \left(\frac{p_i}{P_I} \right)^{-\frac{1}{1-\beta}} \frac{A}{P_I} \tag{2.14}$$

where p_i is the price of final good i, A are aggregate expenditures, and $P_I \equiv \left(\int_0^M p_i^{-\frac{\beta}{1-\beta}} di \right)^{-\frac{1-\beta}{\beta}}$ is the price index of final goods. Since P_I is defined as the numeraire $(P_I \equiv 1)$ the implied demand function for each firm, $Ap_i^{-\frac{1}{1-\beta}}$, in *Section 2.3.2* becomes identical to (2.14). In combination with optimal firm choices in *Section 2.3.3* and market clearing, equilibrium is defined as:

Definition 2.1 *Equilibrium in an economy with homogeneous firms is given by a set of prices $\{p, w_H, w_L\}$, quantities $\{Y, H, L\}$, and level of technology N such that with free entry of firms consumers choose consumption of each final good optimally, firms choose output, level of technology and labor inputs optimally, and labor and product markets clear.*

Note that intermediate inputs do not show up in the definition of equilibrium. However, they are produced within each firm with high- and low-skilled labor that are aggregated on the firm-level to firm-specific high- and low-skilled labor demands. Furthermore, when technology choices are constrained and thus given by the barrier, the set of equations defining the equilibrium is reduced by the optimal firm decision on technology.

2.4.1 Wages Levels, Skill Premium, and Firm numbers

There is free entry of firms and each firm has to incur f units of low-skilled labor to set up production. Adding these market entry cost to production low-skilled labor demand results in a firm's total low-skilled labor demand: $L + f$. The free entry condition,

$$pY - C(Y) - w_L f = 0 \iff (1-\beta)pY = w_L f, \tag{2.15}$$

fixes the wage level given a firm's revenue. The latter is derived by multiplying the optimal price (2.8) by the optimal output (2.7) and using the expression of average unit costs $\bar{K}_N$:

$$pY = \beta^{\frac{\beta}{1-\beta}} A N^{\frac{\kappa\beta}{1-\beta}} w_L^{\frac{\beta}{\beta-1}} \bar{w}^{\frac{N\beta}{\mu(\beta-1)}} (1 - \varepsilon_{\bar{K}_N}\sigma)^{\frac{\beta}{\sigma(\beta-1)}}. \tag{2.16}$$

Plugging this expression into the free entry condition (2.15) and considering total labor income ($w_L L^s + w_H H^s = A$) results in the wage level

$$w_L = \beta N^{\kappa} \bar{w}^{-\frac{T}{\mu}} (1 - \varepsilon_{\bar{K}_N}\sigma)^{-\frac{1}{\sigma}} \left(\frac{(1-\beta)(L^s + \bar{w}H^s)}{f} \right)^{\frac{1-\beta}{\beta}} \tag{2.17}$$

which is a function of labor endowments, parameters, the barrier to technology adoption, and the skill premium.

The wage gap and, implicitly, the high-skilled wage are derived from setting relative labor supply equal to relative labor demand, using production labor demands ((2.11) and (2.12)) and the zero profit condition (2.15) in a firm's revenue where $pY = Ap^{\frac{\beta}{\beta-1}}$:

$$\frac{H^S}{L^S} = \frac{MH}{M(L+f)} = \frac{1}{\bar{w}} \frac{\varepsilon_{\bar{K}_N}}{\frac{\ln \bar{w}}{\beta} - \varepsilon_{\bar{K}_N}}. \tag{2.18}$$

If the barrier does not constrain the technology choice, the above skill premium equation collapses to $\frac{H^S}{L^S} = \frac{1}{\bar{w}} \frac{\kappa}{\frac{\ln \bar{w}}{\beta} - \kappa}$ exhibiting the properties presented in the first chapter. However, whenever firms' optimal technology choice is restricted by the barrier, the implied wage gap in (2.18) depends on the barrier which has important repercussions in the following.

Plugging the free entry condition (2.15) into the equality of household income and total expenditures ($w_L L^s + w_H H^s = MpY$) results in the number of firms

$$M = \frac{1-\beta}{f}(L^s + \bar{w}H^s).$$

Clearly, firm numbers rise in the absolute supply of labor and decrease in fixed costs. They depend on the barrier to technology adoption when the latter determines the skill premium, i.e. when firms are restricted in their technology choice. Note further that a higher M increases variety and, as a consequence, welfare of the representative household.

2.4.2 Determinants of Technology Restriction

The relative endowment of high-skilled labor and the scope for technology in production determine the skill premium and, simultaneously, a firm's technology level. Whether the latter is chosen optimally or restricted by the barrier to technology adoption is analyzed in the following proposition.

Proposition 2.4 *If and only if it holds that*

$$\frac{H^S}{L^S} > \exp\left(\frac{-2\kappa\frac{\mu}{T}}{1-\kappa\sigma}\right)\frac{1-\kappa\sigma}{\frac{2}{\beta}\frac{\mu}{T}-1+\kappa\sigma} \tag{2.19}$$

firms' technology choices are constrained by the barrier to technology adoption. In particular, the latter precludes the use of better technologies if it is rather restrictive, high-skilled labor is relatively abundant, firms are endowed with a rather great scope for technology in production, or the elasticity of substitution between final goods is relatively small.

The proof is given in Appendix 2.7.5. A more restrictive barrier to technology adoption is, ceteris paribus, more likely to constrain a firm's technology choice[14]. A smaller range of feasible production techniques decreases firms' chances to adopt the most efficient technologies. On the other hand, a country's labor endowments have an indirect impact on the fact whether the barrier is binding or not. A greater relative endowment of high-skilled labor implies ceteris paribus a lower skill premium which, in turn, decreases costs

[14]As $T \leq \mu$, a firm cannot choose a 'not defined' technology level of $N > \mu$. See the first chapter for an analysis of $N \leq \mu$ in the unconstrained case.

of technology adoption. Firms would choose a higher optimal level of technology in production and would be more prone to become restricted by the barrier. In the same line, a higher scope for technology in production increases the benefits of more sophisticated production techniques. The optimally chosen technology level rises and, consequently, being restricted in their technology choice becomes more likely for firms. A different mechanism applies to the elasticity of substitution between final products. A less elastic demand (i.e. a smaller β) implies greater operating profits what induces more firms to enter the market. As fixed costs are paid in units of low-skilled labor, relative skill demand decreases and the skill premium shrinks. This reduces the cost of technology adoption as in the case of a greater relative skill endowment and raises the level of the optimally chosen technology.

2.4.3 Impact of Lower Barriers to Technology Adoption on Firms and Welfare

Beside vested interests of groups, inefficient institutions and bureaucratic regulations are often the underlying causes of barriers to technology adoption (Parente and Prescott, 2002). Their removal requires dedicated policy reforms which are usually tackled step-by-step. My model follows this process by analyzing the marginal impact of a reduction in barriers on a country's economic variables.

Proposition 2.5 *The skill premium, a firm's productivity, the number of firms, total labor income, and a country's welfare increase when the barrier is lowered (i.e. if T increases).*

The proof is given in Appendix 2.7.5. If firms are not restricted in their choice of technology, the barrier has no impact on any firm decision or aggregated variable. However, if the barrier constrains effectively firms' decisions, it has severe consequences. Instead of choosing their optimal level of technology in production, N^*, firms' production techniques are restricted to $T < N^*$. When the barrier is lowered, i.e. through a policy change, firms adopt higher and more efficient levels of technology that boost their productivities. However, the implementation of more sophisticated production techniques is relatively more high-skilled labor intensive. As a result, relative high-skill demand increases and, as labor supply is fixed, necessarily the skill premium. Nevertheless, the total impact on firm-level productivity is positive since gains from more advanced technologies outweigh the labor costs increase that results from a combination of higher skill intensity and a widening wage gap. Furthermore, the rise in productivity increases firms' revenues and makes market entry more profitable. As a consequence, more firms enter the market and set up production. However, perfect competition on labor markets imply that higher productivities are passed on to workers via higher wages resulting in greater total labor income. An inherent property of models having a representative consumer with CES utility is that total labor income directly translates into the representative household's utility or, in other words, into welfare. As a result, a gradual improve in a country's regulatory framework that implies lower barriers to technology adoption increases overall welfare.

2.5 Heterogeneous Firms Equilibrium

The above analysis focuses on the equilibrium impact of lower barriers to technology adoption on skill premia, technology levels, and productivity. However, the assumption of homogeneous firms excludes any difference in firm-level reactions although the disparities may be huge. The majority of the economic literature agrees on substantial heterogeneity in productivity across firms (Bernard and Jensen, 1995, 1999), which is introduced in the present model through differences in firms' scopes for technology in production. A direct implication is that firms are heterogeneous with respect to the chosen level of technology, production, productivity, and relative skilled labor demand.

In the following, I analyze the impact of a lower barrier to technology adoption on an economy populated by firms of technology type κ_h (high-productivity firms) and, respectively, type κ_l (low-productivity firms), where $\kappa_h > \kappa_l$. Prior to market entry, a firm may choose its type. Benefits in terms of production are higher in the case of a greater scope for technology. However, this requires regularly a higher investment in research and development. As a consequence, firms of the technology type κ_h incur higher fixed costs than firms of technology type κ_l, implying $f_h > f_l$. $\frac{f_h}{f_l}$ is defined as relative fixed costs and $\frac{N_h}{N_l}$

represents the technology gap of more to less productive firms. In particular, enormous relative fixed costs may prevent any firm to choose the high type. If the difference in the scope for technology in production is very large, the low type is never chosen. In the following, I will first assume that parameters are such that both types coexist and in a second step, I will analyze the conditions of coexistence in more detail.

2.5.1 Impact of Lower Barriers to Technology Adoption on the Skill Premium and Technologies

Given that more and less productive firms enter the market and produce, the expected return of each investment strategy is zero and firms are consequently indifferent which strategy to choose.

Definition 2.2 *Equilibrium with heterogeneous firms is given by a set of prices* $\{p_h, p_l, w_H, w_L\}$*, quantities* $\{Y_h, Y_l, H_h, H_l, L_h, L_l\}$*, and levels of technology* $\{N_h, N_l\}$ *such that with free entry of firms consumers choose consumption of each final good optimally, firms choose output, level of technology and labor inputs optimally, while labor and product markets clear.*

While the above equilibrium definition is of a more general nature, I will restrict my analysis to the case where the technology choice of h-firms is constrained by the barrier T. In the spirit of Parente and Prescott (2002), barriers to technology adoption are imposed by institutions such that technology choices of high-productivity firms are restricted. In this way, less productive firms avoid an increased competition[15] and protect their vested interests. As a consequence, h-firms' first order condition of the optimal technology choice drops from the set of equilibrium equations and N_h is set to T.

Different to the homogeneous firms economy with free entry, the skill premium is not determined by relative total labor demands and supply. Rather, it is derived from the

[15]Note that in this class of CES-utility models competition occurs exclusively on labor markets, i.e. higher wages imply an increased competition.

relation of free entry conditions $p_h Y_h = \frac{w_L f_h}{1-\beta}$ and $p_l Y_l = \frac{w_L f_l}{1-\beta}$[16]:

$$\phi_{\Delta}^{\frac{\beta}{1-\beta}} = \frac{f_h}{f_l}. \tag{2.20}$$

While the above implicit skill premium equation holds irrespective whether the technology barrier binds or not, its explicit functional form differs.

Proposition 2.6 *Assume that high-productivity firms are restricted in their technology choice and that the technology barrier is lowered, i.e. T increases. Then, the skill premium rises, $\frac{d\bar{w}}{dT} = \frac{\bar{w}\ln\bar{w}}{T}\frac{\kappa_h - \varepsilon_{\bar{K}_T}}{\varepsilon_{\bar{K}_T} - \kappa_l} > 0$, and the technology gap, $\frac{\partial\left(\frac{T}{N_l}\right)}{\partial T} = \frac{\kappa_h - \kappa_l}{N_l(\varepsilon_{\bar{K}_T} - \kappa_l)} > 0$, widens. However, relative productivities remain constant.*

The proof is given in Appendix 2.7.6. Lower barriers to technology adoption enable high-productivity firms to approach or even attain their optimal levels of technology in production while having no direct effect on l-firms' choices. However, higher technology levels of h-firms imply a greater relative demand of high-skilled labor and drive up the skill premium. As a consequence, l-firms face higher labor costs for maintaining their technology level and are finally forced to downgrade their production techniques.

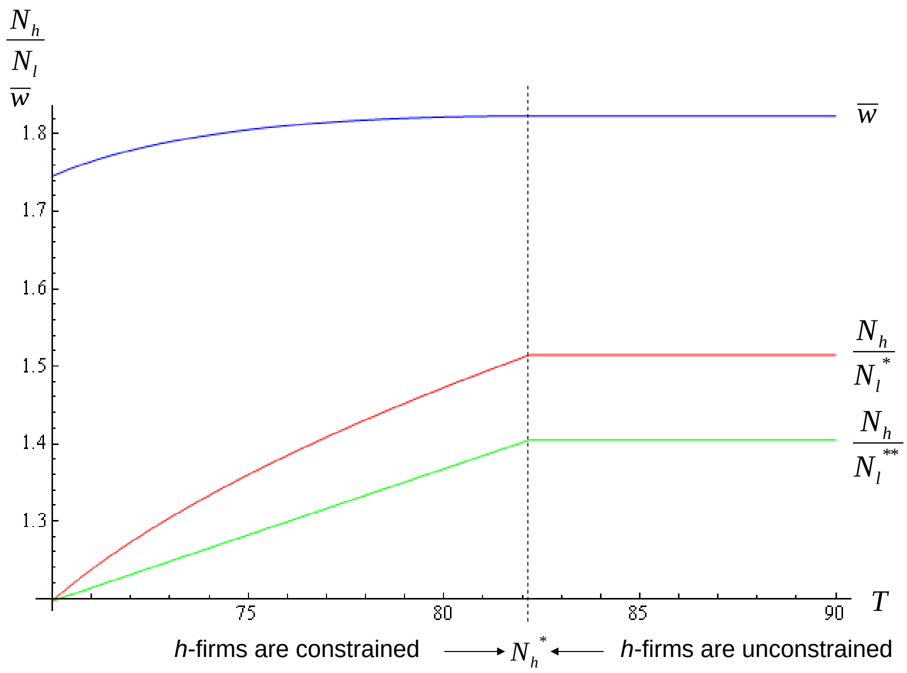
This is illustrated by a simulation in *Figure 2.1*[17]. N_l^* depicts the optimal technology choice of an l-firm for any wage gap while N_l^{**} constitutes its optimal choice given a constant skill premium $\bar{w}(T = 70)$. The increase in the technology gap $\frac{N_h}{N_l^*}$ is considerably sharper than that of $\frac{N_h}{N_l^{**}}$ since the latter does not include downgrades caused by widening wage gaps. The difference in the two technology gaps increases for lower barriers and becomes agnostic to further reductions once high-productivity firms have reached their optimal level of technology. Although lower barriers to technology adoption lead to an increase in the technology gap, its positive impact on the productivity difference is exactly canceled by the simultaneous skill premium rise[18]. A higher level of technology in production leads to a rise in high-productivity firms' relative skill demand. This, in combination

[16] See the first chapter for an analysis of how that relates to the Rybczynski Theorem and how the technology choices of different firms are related through factor markets.

[17] Parameters are $\kappa_h = 0.24$, $\kappa_l = 0.16$, $\sigma = 1/3$, $\beta = 0.75$, $f_h/f_l = 2.75$, $H^s = 15$, $L^s = 85$, and $\mu = 100$. Remark that Acemoglu et al. (2007) compute implicit values of $\kappa = 0.135$ and $\kappa = 0.25$ for the U.S..

[18] Further details are given at the end of the proof of *Pproposition 2.6.*

Figure 2.1: Technology Gap and Skill Premia



The impact of lower barriers to technology adoption on the technology gap and the skill premium. To the left of N_h^*, h-firms are constrained by the barrier T while to the right, they are not. The blue graph depicts the wage gap, the red $\frac{N_h}{N_l^*}$, and the green $\frac{N_h}{N_l^{**}}$.

with the skill premium increase, has a strong dampening effect on their productivity. On the other hand, low-productivity firms downgrade their level of technology and, consequently, their relative skill demand as a reaction to the widening wage gap. In this way, they alleviate the negative impact of the wage cost increase on their level of productivity.

Note that the above result of a constant productivity gap differs from the firm-level equilibrium where firms consider wages as given and lower barriers imply growing differences in productivities. In essence, the existence of an equilibrium with positive numbers of both types of firms requires that the productivity gap is unaffected by altering the barrier. Otherwise, comparative static exercises for firm differences cannot be carried out as an increase in the barrier would imply an economy without low-productivity firms.

2.5.2 Endogenous Numbers of Firms

Whether homogeneous or heterogeneous firms populate the economy depends in fact on the set of a country's parameters and endowments (κ_h, κ_l, β, σ, H^s, L^s, T). They determine simultaneously whether both types of firms enter or whether one type is precluded from entering profitably the economy. For a more detailed analysis of firm entry decisions, numbers of more and less productive firms are computed explicitly. Furthermore, conditions for simultaneous or exclusive entry are derived.

In a first step, the number of h-firms is fixed. Using the free entry condition of l-firms, $(1-\beta)p_l Y_l = w_L f_l$, the skill premium equation (2.20), and labor renumeration ($A = w_L L^S + w_H H^S$) in product market clearing ($A = M_l p_l Y_l + M_h p_h Y_h$) results in the number of l-firms

$$M_l = \frac{(1-\beta)(L^S + \bar{w}H^S)}{f_l} - M_h \phi_\Delta^{\frac{\beta}{1-\beta}}. \tag{2.21}$$

Relating high- and low-skilled labor market clearing implies

$$\frac{H^s}{L^s} = \frac{M_l H_l + M_h H_h}{M_l(L_l + f_l) + M_h(L_h + f_h)}.$$

Next, using the demands of low- (2.12) and high-skilled labor (2.11) within each firm, while considering in addition free entry of l-firms and the number of l-firms (2.21), results with the skill premium equation (2.20) in the number of high-productivity firms

$$M_h = \frac{(1-\beta)(\bar{w}H^S(\frac{\ln(\bar{w})}{\beta} - \kappa_l) - \kappa_l L^S)}{f_h(\varepsilon_{\bar{K}_T} - \kappa_l)}. \tag{2.22}$$

Finally, plugging the above expression into (2.21) results in the number of low-productivity firms:

$$M_l = \frac{(1-\beta)(\varepsilon_{\bar{K}_T} L^S - \bar{w}H^S(\frac{\ln(\bar{w})}{\beta} - \varepsilon_{\bar{K}_T}))}{f_l(\varepsilon_{\bar{K}_T} - \kappa_l)}. \tag{2.23}$$

The following proposition determines conditions under which more and/or less productive firms enter the market.

Proposition 2.7 *Holding all other parameters constant,* $\forall \frac{f_h}{f_l} \in \left(\left(\frac{f_h}{f_l}\right)^*, \left(\frac{f_h}{f_l}\right)^{**}\right)$*, where* $\left(\frac{f_h}{f_l}\right)^* < \left(\frac{f_h}{f_l}\right)^{**}$*, low-productivity as well as high-productivity firms enter the market. Furthermore,* $\forall \frac{f_h}{f_l} \leq \left(\frac{f_h}{f_l}\right)^*$*, exclusively high-productivity firms and* $\forall \frac{f_h}{f_l} \geq \left(\frac{f_h}{f_l}\right)^{**}$*, exclusively low-productivity firms enter.*

The proof is given in Appendix 2.7.6. Essentially, the above proposition describes the ranges of fixed costs that imply either the exclusive entry of high-productivity or low-productivity firms or the simultaneous market entry of both. Relative fixed costs above $\left(\frac{f_h}{f_l}\right)^{**}$ preclude the entry of h-firms and imply an economy populated by l-firms. However, relative fixed costs below $\left(\frac{f_h}{f_l}\right)^*$ involves that high-productivity firms' technological advantage outweighs their fixed costs disadvantage such that no firm chooses to become a low-productivity firm. Given the scopes for technology in production and other parameters, there exists a range of 'coexistence', $\left(\left(\frac{f_h}{f_l}\right)^*, \left(\frac{f_h}{f_l}\right)^{**}\right)$, where both types of firms enter the economy.

2.5.3 Impact of Lower Barriers to Technology Adoption on Wages and Welfare

Although the skill premium rises it remains unclear whether low-skilled workers only lose in relative terms or whether lowering barriers to technology adoption leaves them worse off. Plugging firm-level labor demands ((2.11), (2.12)) and firm numbers ((2.22), (2.23)) into high-skilled labor market clearing ($M_l H_l + M_h H_h = H^s$) and using firms' revenue functions ((2.16) for h- and l-firms, respectively) results in the low-skilled wage level

$$w_L = \beta T^{\kappa_h} \bar{w}^{-\frac{T}{\mu}} (1 - \varepsilon_{\bar{K}_T} \sigma)^{-\frac{1}{\sigma}} \left(\frac{(1-\beta)(L^s + \bar{w} H^s)}{f_h} \right)^{\frac{1-\beta}{\beta}}. \tag{2.24}$$

w_L differs from the case of homogeneous firms (2.17) with respect to the implicit function that determines the skill premium and with respect to fixed entry costs.

Proposition 2.8 *A country's welfare increases if barriers to technology adoption are lowered. The low-skilled wage decreases in lower barriers if the scope for technology in production of low-productivity firms is relatively big, and low-skilled labor is relatively abundant:* $\frac{\partial w_L}{\partial T} = \frac{w_L}{T}\frac{\kappa_h - \varepsilon_{\bar{K}_T}}{\varepsilon_{\bar{K}_T} - \kappa_l}\left(\frac{1-\beta}{\beta}\frac{\bar{w}H^s}{L^s + \bar{w}H^s}\ln\bar{w} - \kappa_l\right)$. *The high-skilled wage increases in lower barriers to technology adoption.*

The proof is given in Appendix 2.7.6. Lower barriers to technology adoption enable high-productivity firms to improve on their level of technology in production. Since high-skilled labor is complementary to more sophisticated production techniques, its demand and, consequently, its wage level increases. On the other hand, the increase in the skill premium downgrades the technology choice of low-productivity firms, implying a dampening effect on the high-skilled wage. Nevertheless, a decrease in barriers increases overall welfare of a country since more productive firms are able to use a production technique that is closer to their optimal choice, N_h. Moreover, since more productive high-skilled workers are shifted towards the more productive firms, country-level efficiency increases and, hence, aggregated output.

The impact of lower barriers to technology adoption on the low-skilled wage is less clear-cut. Since high-productivity firms implement a higher level of technology the high-skill complementarity implies that demand of low-skilled labor decreases. Given that low-skilled are relatively abundant, a decrease in the wage level equilibrates the low-skilled labor market. A great scope for technology in production of low-productivity firms implies that they operate with a high level of technology in production. In case of a downgrade of production techniques, l-firms will still produce with sophisticated technologies, thus increasing the low-skilled labor demand only by little which does not compensate for the lowered demand of h-firms.

2.6 Conclusion

In this chapter of my dissertation, I analyze the impact of reducing barriers to technology adoption on the endogenous technology choices of heterogeneous firms, the skill premium, and a country's welfare. Firms are heterogeneous with respect to their scope for skill-complementary technology in production. High-productivity firms have an inherent advantage in the use of technology in production and choose in optimum more sophisticated production techniques than low-productivity firms. However, bad institutions or regulatory policies that protect the vested interests of the latter impose a barrier that constrains high-productivity firms to use technologies in production well inferior to their optimal choice. Whenever a policy reform loosens the restrictions, high-productivity firms face lower barriers and adopt more sophisticated techniques. In contrast, there exists no direct impact on low-productivity firms. However, since technology is skill-complementary the relative skill demand of high-productivity firms rises and the skill premium increases. Consequently, low-productivity firms with already low levels of technology have to downgrade production techniques since the costs of technology adoption increase. As a consequence, the technology gap between more and less productive firms widens.

Although some firms are induced to produce with less productive technologies a country's overall welfare increases. Hence, this study, in line with most of the literature, emphasizes the importance of lowering barriers to technology adoption to improve output per capita in emerging and developing countries. However, the detrimental effects on out-of-date industries and their employees have to be taken into account. The welfare gains in my analysis crucially depend on increased labor market competition that reallocates in particular high-skilled workers to more productive industries. In the presence of labor market frictions, welfare losses would occur from a hindered reallocation which would lead to transitional unemployment. Although gains from lower barriers should still prevail, further research is needed to clarify the impact of lower barriers to technology adoption on the welfare level of workers.

2.7 Appendix A2

2.7.1 Derivation of Optimal Quantities of Intermediate Inputs

This section contains a derivation of the optimal x_j for any $N \in (0,T]$. The first order maximization conditions $\forall j \in [0,N]$ derived from (2.4) are:

$$\beta A^{1-\beta} Y^{\beta-1} \frac{\partial Y}{\partial x_j} = k_j \quad \forall j \in [0,N]\,. \tag{A2.1}$$

From the definition of Y I calculate

$$\frac{\partial Y}{\partial x_j} = \frac{x_j^{\frac{-1}{1+\sigma}} Y}{\int_0^N x_j^{\frac{\sigma}{1+\sigma}} dj}. \tag{A2.2}$$

Using (A2.2) in (A2.1), I obtain, for each pair (j,j'),

$$\frac{x_j}{x_{j'}} = \left[\frac{k_j'}{k_j}\right]^{1+\sigma}. \tag{A2.3}$$

Plugging (A2.3) back in (A2.2) results in $\frac{\partial Y}{\partial x_j} = \frac{x_j^{-1} Y}{k_j^{\sigma} \int_0^N k_j^{-\sigma} dj}$. Using this in (A2.1) implies $\beta A^{1-\beta} Y^{\beta} \frac{x_j^{-1}}{k_j^{\sigma} N \bar{K}_N^{-\sigma}} = k_j$ as $\int_0^N k_j^{-\sigma} dj = N\bar{K}_N^{-\sigma}$. Simple rearranging shows that

$$x_j = \beta A^{1-\beta} Y^{\beta} N^{-1} \bar{K}_N^{\sigma} k_j^{-\sigma-1}. \tag{A2.4}$$

Plugging (A2.4) in the production function (2.1) and solving for Y leads to $Y = \beta^{\frac{1}{1-\beta}} A N^{\frac{\kappa}{1-\beta}} \bar{K}_N^{-\frac{1}{1-\beta}}$ which is (2.7) in the main text. Using this result in (A2.4) and rearranging implies $x_j = \beta^{\frac{1}{1-\beta}} A N^{\frac{\beta(\kappa+1)-1}{1-\beta}} \bar{K}_N^{\sigma-\frac{\beta}{1-\beta}} k_j^{-1-\sigma}$ which is (2.5) in the main text. Using optimal firm output (2.7) as well as optimal intermediates inputs (2.5) and the definition of productivity (2.9) involves a new form of the firm's profit function for any given $N \in (0,\mu]$: $\Pi_N = \beta^{\frac{\beta}{1-\beta}} A \phi^{\frac{\beta}{1-\beta}} (1-\beta)$. Note that a firm's profit is not yet maximized with respect to the level of technology. The first derivative with respect to N implies $\frac{\partial \Pi_N}{\partial N} = \frac{\Pi_N}{N}(\kappa - \varepsilon_{\bar{K}_N})$ where I use the fact that $\frac{\partial \phi}{\partial N} = \phi\left(\frac{\kappa}{N} - \frac{\frac{\partial \bar{K}_N}{\partial N}}{\bar{K}_N}\right) = \frac{\phi}{N}(\kappa - \varepsilon_{\bar{K}_N})$.

2.7.2 Properties of the Elasticity of Average Unit Costs

The elasticity of average unit costs reads as

$$\varepsilon_{\bar{K}_N} = \frac{1}{\sigma} - \frac{\frac{N}{\mu}\ln\bar{w}}{\bar{w}^{\sigma\frac{N}{\mu}} - 1}. \tag{A2.5}$$

Note that if the firm is technology constrained, $N = T$. Furthermore, within this section I assume that $\bar{w}$ is constant.

<u>Derivative with respect to N:</u>

Taking the derivative with respect to N leads to

$$\begin{aligned}\frac{\partial\varepsilon_{\bar{K}_N}}{\partial N} &= \frac{\ln\bar{w}}{\mu}\frac{\bar{w}^{\sigma\frac{N}{\mu}}\ln(\bar{w})\sigma\frac{N}{\mu} - (\bar{w}^{\sigma\frac{N}{\mu}} - 1)}{(\bar{w}^{\sigma\frac{N}{\mu}} - 1)^2} \\ &= \frac{1}{N}\left(\frac{1}{\sigma} - \varepsilon_{\bar{K}_N}\right)\left(\bar{w}^{\sigma\frac{N}{\mu}}(1 - \varepsilon_{\bar{K}_N}\sigma) - 1\right)\end{aligned} \tag{A2.6}$$

and, consequently, since $\frac{1}{\sigma} > \varepsilon_{\bar{K}_N}$ due to $\frac{1}{\sigma} > \kappa > \varepsilon_{\bar{K}_N}$: $\frac{\partial\varepsilon_{\bar{K}_N}}{\partial N} > 0 \iff \bar{w}^{\sigma\frac{N}{\mu}}(1 - \varepsilon_{\bar{K}_N}\sigma) - 1 > 0 \iff \bar{w}^{\sigma\frac{N}{\mu}}\sigma\frac{N}{\mu}\ln(\bar{w}) > \bar{w}^{\sigma\frac{N}{\mu}} - 1$. Note that $\bar{w}^{\sigma\frac{N}{\mu}} = e^{\ln(\bar{w})\sigma\frac{N}{\mu}}$ and e^x for $x \in \mathbb{R}$ is defined as the power series $e^x \equiv \sum_{n=0}^{\infty}\frac{x^n}{n!}$. Therefore, I can rewrite $\bar{w}^{\sigma\frac{N}{\mu}}$ as $\left(1 + \ln(\bar{w})\sigma\frac{N}{\mu} + \frac{1}{2}\left(\ln(\bar{w})\sigma\frac{N}{\mu}\right)^2 + \dots\right)$ and the above inequality reads as

$$\begin{aligned} & \left(1 + \ln(\bar{w})\sigma\frac{N}{\mu} + \frac{1}{2}\left(\ln(\bar{w})\sigma\frac{N}{\mu}\right)^2 + \dots\right)\ln(\bar{w})\sigma\frac{N}{\mu} \\ & > 1 + \ln(\bar{w})\sigma\frac{N}{\mu} + \frac{1}{2}\left(\ln(\bar{w})\sigma\frac{N}{\mu}\right)^2 + \dots - 1 \\ \iff\quad & \frac{1}{2}\left(\ln(\bar{w})\sigma\frac{N}{\mu}\right)^2 + \frac{1}{2}\left(\ln(\bar{w})\sigma\frac{N}{\mu}\right)^3 + \frac{1}{6}\left(\ln(\bar{w})\sigma\frac{N}{\mu}\right)^4 + \dots \\ & > \frac{1}{6}\left(\ln(\bar{w})\sigma\frac{N}{\mu}\right)^3 + \frac{1}{24}\left(\ln(\bar{w})\sigma\frac{N}{\mu}\right)^4 + \dots \end{aligned}$$

which holds and implies $\frac{\partial\varepsilon_{\bar{K}_N}}{\partial N} > 0$.

Derivative with respect to $\bar{w}$:

Taking the derivative with respect to $\bar{w}$ leads to

$$\begin{aligned}
\frac{\partial \varepsilon_{\bar{K}_N}}{\partial \bar{w}} &= \frac{1}{\bar{w}} \frac{\ln(\bar{w})\sigma\left(\frac{N}{\mu}\right)^2 \bar{w}^{\sigma\frac{N}{\mu}} - \frac{N}{\mu}\left(\bar{w}^{\sigma\frac{N}{\mu}} - 1\right)}{(\bar{w}^{\sigma\frac{N}{\mu}} - 1)^2} \\
&= \frac{1}{\bar{w}\ln(\bar{w})}\left(\frac{1}{\sigma} - \varepsilon_{\bar{K}_N}\right)\left(\bar{w}^{\sigma\frac{N}{\mu}}(1 - \varepsilon_{\bar{K}_N}\sigma) - 1\right) > 0 \qquad \text{(A2.7)}
\end{aligned}$$

as $\left(\bar{w}^{\sigma\frac{N}{\mu}}(1 - \varepsilon_{\bar{K}_N}\sigma) - 1\right) > 0$ from $\frac{\partial \varepsilon_{\bar{K}_N}}{\partial N} > 0$.

2.7.3 Derivation of Production Factor Demands

Rewriting $\varepsilon_{\bar{K}_N}$ for any $N \in (0, \mu)$ implies

$$\varepsilon_{\bar{K}_N} = \frac{1}{\sigma} - \frac{\frac{N}{\mu}\ln\bar{w}}{\bar{w}^{\sigma\frac{N}{\mu}} - 1} \iff \frac{1 - \bar{w}^{-\sigma\frac{N}{\mu}}}{\frac{N}{\mu}\ln(\bar{w})} = \frac{1}{\bar{w}^{\sigma\frac{N}{\mu}}\left(\frac{1}{\sigma} - \varepsilon_{\bar{K}_N}\right)}. \qquad \text{(A2.8)}$$

Similarly, average unit costs can be written as

$$\bar{K}_N = w_L \bar{w}^{\frac{N}{\mu}}\left(1 - \varepsilon_{\bar{K}_N}\sigma\right)^{\frac{1}{\sigma}}. \qquad \text{(A2.9)}$$

Demand of high-skilled labor to produce intermediate input j, H_j, with the production function (2.2) is given through cost minimization (see the first chapter) and reads as

$$H_j = x_j \frac{j}{\mu}\bar{w}^{\frac{j}{\mu}-1} = \beta^{\frac{1}{1-\beta}} A N^{\frac{\beta(\kappa+1)-1}{1-\beta}} \bar{K}_N^{\sigma - \frac{\beta}{1-\beta}} w_L^{-1-\sigma} \frac{j}{\mu}\bar{w}^{-\sigma\frac{j}{\mu}-1} \qquad \text{(A2.10)}$$

Taking the integral $\int_0^N dj$ and using $k_j = w_L \bar{w}^{\frac{j}{\mu}}$ leads to

$$H = \int_0^N H_j dj = \beta^{\frac{1}{1-\beta}} A N^{\frac{\beta(\kappa+1)-1}{1-\beta}} \bar{K}_N^{\sigma - \frac{\beta}{1-\beta}} w_L^{-1-\sigma} \frac{1}{\mu\bar{w}} \int_0^N j\bar{w}^{-\sigma\frac{j}{\mu}} dj$$

where integration by parts results in

$$H = \beta^{\frac{1}{1-\beta}} A N^{\frac{\beta(\kappa+1)-1}{1-\beta}} \bar{K}_N^{\sigma - \frac{\beta}{1-\beta}} w_L^{-1-\sigma} \frac{\frac{1 - \bar{w}^{-\frac{N}{\mu}\sigma}}{\ln\bar{w}\frac{\sigma}{\mu}} - N\bar{w}^{-\frac{N}{\mu}\sigma}}{\sigma\bar{w}\ln\bar{w}}. \qquad \text{(A2.11)}$$

Using (A2.8) implies $H = \beta^{\frac{1}{1-\beta}} AN^{\frac{\beta(\kappa+1)-1}{1-\beta}} \bar{K}_N^{\sigma-\frac{\beta}{1-\beta}} w_L^{-1-\sigma} \frac{N}{\sigma\bar{w}\ln\bar{w}} \bar{w}^{-\sigma\frac{T}{\mu}} \frac{\frac{1}{\sigma}-\left(\frac{1}{\sigma}-\varepsilon_{\bar{K}_T}\right)}{\frac{1}{\sigma}-\varepsilon_{\bar{K}_T}}$ while using the optimal price $p = \frac{\bar{K}_T}{N^\kappa\beta}$ of (2.8) and simplifying results in

$$H = \beta A p^{\frac{\beta}{\beta-1}} \bar{K}_N^{\sigma} \frac{w_L^{-\sigma}}{w_H \ln\bar{w}} \bar{w}^{-\sigma\frac{T}{\mu}} \frac{\varepsilon_{\bar{K}_T}}{1-\varepsilon_{\bar{K}_T}\sigma}.$$

(A2.9) allows to substitute for $\bar{K}_N$ and simplifying results in $H = \beta A p^{\frac{\beta}{\beta-1}} \frac{\varepsilon_{\bar{K}_N}}{w_H \ln\bar{w}}$. This is (2.11) in the main text. Similarly, L_j is given by

$$\begin{aligned} L_j &= x_j(1-\frac{j}{\mu})\bar{w}^{\frac{j}{\mu}} = \beta^{\frac{1}{1-\beta}} AN^{\frac{\beta(\kappa+1)-1}{1-\beta}} \bar{K}_N^{\sigma-\frac{\beta}{1-\beta}} w_L^{-1-\sigma} \left(1-\frac{j}{\mu}\right) \bar{w}^{-\frac{j}{\mu}\sigma} \\ \text{and} \quad L &= \int_0^N L_j dj = \beta^{\frac{1}{1-\beta}} AN^{\frac{\beta(\kappa+1)-1}{1-\beta}} \bar{K}_N^{\sigma-\frac{\beta}{1-\beta}} w_L^{-1-\sigma} \int_0^N \bar{w}^{-\frac{j}{\mu}\sigma} dj - \bar{w}H \end{aligned}$$

where integrating and using the expression in (A2.11) for H results in

$$\begin{aligned} L &= \beta^{\frac{1}{1-\beta}} AN^{\frac{\beta(\kappa+1)-1}{1-\beta}} \bar{K}_N^{\sigma-\frac{\beta}{1-\beta}} w_L^{-1-\sigma} \frac{\mu\left(1-\bar{w}^{-\frac{N}{\mu}\sigma}\right)\left(1-\frac{1}{\sigma\ln\bar{w}}\right)+N\bar{w}^{-\frac{N}{\mu}\sigma}}{\sigma\ln\bar{w}} \\ &= \beta^{\frac{1}{1-\beta}} AN^{\frac{\beta(\kappa+1)-1}{1-\beta}} \bar{K}_N^{\sigma-\frac{\beta}{1-\beta}} w_L^{-1-\sigma} \frac{N}{\sigma\ln\bar{w}} \left[\frac{1-\bar{w}^{-\frac{N}{\mu}\sigma}}{\frac{N}{\mu}\sigma\ln\bar{w}}(\sigma\ln\bar{w}-1)+\bar{w}^{-\frac{N}{\mu}\sigma}\right]. \end{aligned}$$

Using (A2.8) implies that

$$L = \beta^{\frac{1}{1-\beta}} AN^{\frac{\beta(\kappa+1)-1}{1-\beta}} \bar{K}_N^{\sigma-\frac{\beta}{1-\beta}} w_L^{-1-\sigma} \frac{N}{\sigma\ln\bar{w}} \bar{w}^{-\sigma\frac{T}{\mu}} \frac{\frac{1}{\sigma}(\sigma\ln\bar{w}-1)+\left(\frac{1}{\sigma}-\varepsilon_{\bar{K}_T}\right)}{\frac{1}{\sigma}-\varepsilon_{\bar{K}_T}}$$

while employing the optimal price $p = \frac{\bar{K}_T}{N^\kappa\beta}$ (2.8) and simplifying results in $L = \beta A p^{\frac{\beta}{\beta-1}} \bar{K}_N^{\sigma} \frac{w_L^{-1-\sigma}}{\ln\bar{w}} \bar{w}^{-\sigma\frac{T}{\mu}} \frac{\ln\bar{w}-\varepsilon_{\bar{K}_N}}{1-\varepsilon_{\bar{K}_T}\sigma}$. Then, the use of (A2.9) allows to substitute for $\bar{K}_N$ and further manipulations lead to $L = \beta A p^{\frac{\beta}{\beta-1}} \frac{\ln\bar{w}-\varepsilon_{\bar{K}_N}}{w_L \ln\bar{w}}$. This is (1.12) in the main text.

2.7.4 Proofs for Firm-Level Choices Given Wages

Proof of Proposition 2.2

A second order Taylor approximation of $\kappa = \frac{1}{\sigma} - \frac{\frac{N^*}{\mu}\ln\bar{w}}{\bar{w}^{\sigma\frac{N^*}{\mu}}-1}$ is computed: $N^* \approx \frac{2\kappa\mu}{\ln(\bar{w})(1-\kappa\sigma)}$. This implies that the choice of technology is restricted if and only if $T < \frac{2\kappa\mu}{\ln(\bar{w})(1-\kappa\sigma)}$.

In particular, it must hold that $\frac{2\kappa_l\mu}{\ln(\bar{w})(1-\kappa_l\sigma)} = N_l^* < N_h = T < \frac{2\kappa_h\mu}{\ln(\bar{w})(1-\kappa_h\sigma)}$ for the h-firm being constrained while the l-firm is not. Simple manipulations show that if $\kappa_l < \frac{1}{\frac{2\mu}{\ln(\bar{w})T}+\sigma} < \kappa_h$, the h-firm is constrained while the l-firm is not. Clearly, the condition $\kappa_h < 1/\sigma$ still holds.

Proof of Proposition 2.3

Assume that the firm is constrained in its technology choice by the barrier.

Proof of an increase in productivity due to an increase in T:

The derivative of firm productivity (2.9) with respect to the technology barrier in case of a binding barrier reads as: $\frac{\partial\phi}{\partial T} = \phi\left(\frac{\kappa}{T} - \frac{\ln\bar{w}}{\mu} + (1-\sigma\varepsilon_{\bar{K}_T})^{-1}\frac{\partial\varepsilon_{\bar{K}_T}}{\partial T}\right)$. Plugging in $\frac{\partial\varepsilon_{\bar{K}_T}}{\partial T}$ given wages and $\varepsilon_{\bar{K}_T}$ from *Appendix 2.7.2* results in $\frac{\partial\phi}{\partial T} = \frac{\phi}{T}(\kappa - \varepsilon_{\bar{K}_T})$.

Proof of a decrease in productivity (2.9) due to an increase in $\bar{w}$:

The derivative of firm productivity (2.9) with respect to the skill premium in case of a binding barrier reads as $\frac{\partial\phi}{\partial\bar{w}} = \phi\left(-\frac{T}{\mu\bar{w}} + (1-\sigma\varepsilon_{\bar{K}_T})^{-1}\frac{\partial\varepsilon_{\bar{K}_T}}{\partial\bar{w}}\right)$. Plugging in $\frac{\partial\varepsilon_{\bar{K}_T}}{\partial\bar{w}}$ and $\varepsilon_{\bar{K}_T}$ from *Appendix 2.7.2* implies that $\frac{\partial\phi}{\partial\bar{w}} = -\frac{\varepsilon_{\bar{K}_T}\phi}{\bar{w}\ln\bar{w}} < 0$.

Proof of an increase in relative production labor demands due to an increase in T:

The derivative of relative production labor demands (2.13) with respect to the technology barrier in case of a binding barrier reads as

$$\frac{\partial\left(\frac{H}{L}\right)}{\partial T} = \frac{\frac{\partial\varepsilon_{\bar{K}_T}}{\partial T}}{\bar{w}}\frac{\ln\bar{w}}{(\ln\bar{w}-\varepsilon_{\bar{K}_T})^2} > 0,$$

since $\frac{\partial\varepsilon_{\bar{K}_T}}{\partial T} > 0$ from *Appendix 2.7.2*.

Proof of the impact of a higher T on productivity differences:

When the h-firm is technology restricted while the l-firm is not, ϕ_Δ becomes

$$\phi_\Delta = \frac{T^{\kappa_h}}{N_l^{\kappa_l}}\bar{w}^{-\frac{T-N_l}{\mu}}\left(\frac{1-\kappa_l\sigma}{1-\varepsilon_{\bar{K}_T}\sigma}\right)^{\frac{1}{\sigma}} \tag{A2.12}$$

and, consequently, the derivative with respect to T holding $\bar{w}$ constant and using $\frac{\partial\varepsilon_{\bar{K}_T}}{\partial T}$

given wages and $\varepsilon_{\bar{K}_T}$ from *Appendix 2.7.2* results in

$$\begin{aligned}\frac{\partial \phi_\Delta}{\partial T} &= \phi_\Delta \left(\frac{\kappa_h}{T} - \frac{\ln \bar{w}}{\mu} + \frac{\frac{\partial \varepsilon_{\bar{K}_T}}{\partial T}}{1 - \varepsilon_{\bar{K}_T}\sigma} \right) \\ &= \frac{\phi_\Delta}{\sigma T \left(\bar{w}^{\sigma \frac{T}{\mu}} - 1 \right)} \left(-(1-\kappa_h \sigma) \left(\bar{w}^{\sigma \frac{T}{\mu}} - 1 \right) + \sigma \frac{T}{\mu} \ln \bar{w} \right) = \frac{\phi_\Delta}{T} \left[\kappa_h - \varepsilon_{\bar{K}_T} \right] > 0.\end{aligned}$$

Proof of the impacts of a higher $\bar{w}$ on productivity differences:

The derivative of (A2.12) with respect to $\bar{w}$ using $\frac{\partial \varepsilon_{\bar{K}_T}}{\partial \bar{w}}$ given wages and $\varepsilon_{\bar{K}_T}$ from *Appendix 2.7.2* results in

$$\begin{aligned}\frac{\partial \phi_\Delta}{\partial \bar{w}} &= \phi_\Delta \left(\frac{\kappa_l}{\bar{w} \ln \bar{w}} - \frac{T}{\bar{w}\mu} + \frac{\frac{\partial \varepsilon_{\bar{K}_T}}{\partial \bar{w}}}{1 - \varepsilon_{\bar{K}_T}\sigma} \right) \\ &= \frac{\phi_\Delta}{\sigma \bar{w} \ln \bar{w} \left(\bar{w}^{\sigma \frac{T}{\mu}} - 1 \right)} \left(-(1-\kappa_l \sigma) \left(\bar{w}^{\sigma \frac{T}{\mu}} - 1 \right) + \sigma \frac{T}{\mu} \ln \bar{w} \right) = -\frac{\phi_\Delta}{\bar{w} \ln \bar{w}} \left[\varepsilon_{\bar{K}_T} - \kappa_l \right] < 0.\end{aligned}$$

2.7.5 Proofs for Homogeneous Firms

Proof of Proposition 2.4

From *Proposition 2.2* $N^* \approx \frac{2\kappa\mu}{(1-\kappa\sigma)\ln \bar{w}}$. Then, the barrier does not constrain the technology choice if and only if

$$N^* \leq T \iff T \geq \frac{2\kappa\mu}{(1-\kappa\sigma)\ln \bar{w}} \iff \bar{w} \geq \exp\left(\frac{2\kappa \frac{\mu}{T}}{1-\kappa\sigma} \right).$$

Define a threshold skill premium: $\bar{w}^\circ = \exp\left(\frac{2\kappa \frac{\mu}{T}}{1-\kappa\sigma} \right)$. Let's further define the functions

$$\underbrace{\frac{H^S}{L^S}\bar{w}}_{\equiv x(\bar{w})} = \underbrace{\frac{\kappa}{\frac{\ln \bar{w}}{\beta} - \kappa}}_{\equiv y(\bar{w})} \tag{A2.13}$$

where $x(\bar{w})$ is a linear and strictly monotone increasing and $y(\bar{w})$ is a strictly decreasing function for $\bar{w} > e^{\kappa\beta}$. The equilibrium value of $\bar{w}$ is defined as $\bar{w}^*$ what implies $x(\bar{w}^*) = y(\bar{w}^*)$. Furthermore, $\lim_{\bar{w} \to e^{\kappa\beta}} x(\bar{w}) < \lim_{\bar{w} \to e^{\kappa\beta}} y(\bar{w})$.

Therefore, $\forall e^{\kappa\beta} < \bar{w} \leq \bar{w}^*$ it holds that $x(\bar{w}) \leq y(\bar{w})$ while $\forall \bar{w} \geq \bar{w}^*$ it is true that $x(\bar{w}) \geq y(\bar{w})$. Plugging the threshold value $\bar{w}^\circ$ into equation (A2.13) under the assumption that $x(\bar{w}^\circ) \leq y(\bar{w}^\circ)$ results, as a consequence, in a parameter combination that ensures $\bar{w}^* \geq \bar{w}^\circ$. Consequently, a firm's technology choice is not constrained by the frontier if and only if

$$\frac{H^S}{L^S} \leq \underbrace{\exp\left(\frac{-2\kappa\frac{\mu}{T}}{1-\kappa\sigma}\right)}_{<1} \underbrace{\frac{1-\kappa\sigma}{\frac{2}{\beta}\frac{\mu}{T}-1+\kappa\sigma}}_{<1}.$$

The above right hand side increases in T, decreases in κ, and increases in β. The inequality thus does not hold for 'too small' T's, for 'too big' $\frac{H^S}{L^S}$, for 'too big' κ's, or for 'too small' β's.

Proof of Proposition 2.5

Proof of an increase in the wage gap:

From (2.18) define $G = \frac{H^S}{L^S}\bar{w}\frac{\ln \bar{w}}{\beta} - \varepsilon_{\bar{K}_T}\left(1+\frac{H^S}{L^S}\bar{w}\right)$, involving

$$\begin{aligned} \frac{\partial G}{\partial \bar{w}} &= \frac{H^S}{L^S}\frac{\ln \bar{w}}{\beta} + \frac{H^S}{L^S}\frac{1}{\beta} - \frac{\partial \varepsilon_{\bar{K}_T}}{\partial \bar{w}}\left(1+\frac{H^S}{L^S}\bar{w}\right) - \varepsilon_{\bar{K}_T}\frac{H^S}{L^S}, \\ \frac{\partial G}{\partial T} &= -\frac{\partial \varepsilon_{\bar{K}_T}}{\partial T}\left(1+\frac{H^S}{L^S}\bar{w}\right). \end{aligned}$$

As $\frac{d\bar{w}}{dT} = -(\frac{\partial G}{\partial T})/(\frac{\partial G}{\partial \bar{w}})$ and $\frac{\partial \varepsilon_{\bar{K}_T}}{\partial T} > 0$, it suffices to show that $\frac{\partial G}{\partial \bar{w}} > 0$:

$$\begin{aligned} \frac{H^S}{L^S}\frac{\ln \bar{w}}{\beta} + \frac{H^S}{L^S}\frac{1}{\beta} &> \frac{\partial \varepsilon_{\bar{K}_T}}{\partial \bar{w}}\left(1+\frac{H^S}{L^S}\bar{w}\right) + \varepsilon_{\bar{K}_T}\frac{H^S}{L^S} \\ \iff \frac{H^S}{L^S}\frac{\ln \bar{w}}{\beta} + \frac{H^S}{L^S}\frac{1}{\beta} &> \frac{1}{\bar{w}\ln(\bar{w})}\left(\frac{1}{\sigma}-\varepsilon_{\bar{K}_T}\right)\left(\bar{w}^{\sigma\frac{T}{\mu}}(1-\varepsilon_{\bar{K}_T}\sigma)-1\right) \\ &+ \frac{H^S}{L^S}\frac{1}{\ln(\bar{w})}\left(\frac{1}{\sigma}-\varepsilon_{\bar{K}_T}\right)\left(\bar{w}^{\sigma\frac{T}{\mu}}(1-\varepsilon_{\bar{K}_T}\sigma)-1\right) + \varepsilon_{\bar{K}_T}\frac{H^S}{L^S}. \end{aligned}$$

Here, I employed $\frac{\partial \varepsilon_{\bar{K}_T}}{\partial \bar{w}}$ from Section 2.7.2. Using (2.18) and simplifying results in

$$\begin{aligned} \ln \bar{w} + 1 &> \left(\bar{w}^{\sigma\frac{T}{\mu}}(1-\varepsilon_{\bar{K}_T}\sigma)-1\right)\frac{\frac{1}{\sigma}-\varepsilon_{\bar{K}_T}}{\varepsilon_{\bar{K}_T}} + \beta\varepsilon_{\bar{K}_T} \\ \iff \varepsilon_{\bar{K}_T}\sigma(\ln \bar{w} - \beta\varepsilon_{\bar{K}_T}) &> \bar{w}^{\sigma\frac{T}{\mu}}(1-\varepsilon_{\bar{K}_T}\sigma)^2 - 1. \end{aligned}$$

As the left hand side is larger than zero, the above inequality holds if the right hand side is smaller than zero:

$$\bar{w}^{\sigma\frac{T}{\mu}}(1-\varepsilon_{\bar{K}_T}\sigma)^2 < 1 \iff \frac{\bar{w}^{\sigma\frac{T}{\mu}}}{\left(\bar{w}^{\sigma\frac{T}{\mu}}-1\right)^2} < \left(\frac{T}{\mu}\sigma\ln\bar{w}\right)^{-2} \iff \bar{w}^{\sigma\frac{T}{\mu}} - \bar{w}^{-\sigma\frac{T}{\mu}} > \left(\frac{T}{\mu}\sigma\ln\bar{w}\right)^2.$$

Taylor expansions are applied to the last inequality where manipulations imply $2 + \frac{1}{6}\left(\frac{T}{\mu}\sigma\ln\bar{w}\right)^2 + \cdots > \frac{T}{\mu}\sigma\ln\bar{w}$. This holds for all $\frac{T}{\mu}\sigma\ln\bar{w}$ and, consequently, $d\bar{w}/dT > 0$.

Proof of productivity increase:

The derivative of firm productivity with respect to the technology barrier reads as

$$\frac{\partial\phi}{\partial T} = \phi\left(\frac{\varepsilon_{\bar{K}_T}}{T} - (1-\alpha)\frac{\ln\bar{w}}{\mu} + \left(\frac{H^S}{L^S+\bar{w}H^S} + \frac{\alpha T}{\mu\bar{w}}\right)\frac{d\bar{w}}{dT}\right)$$

using endogenous wages and as well as $\frac{\partial\varepsilon_{\bar{K}_T}}{\partial T}$ and defining $\alpha \equiv \frac{(1-\sigma\varepsilon_{\bar{K}_T})\bar{w}^{\sigma\frac{T}{\mu}}-1}{(1-\sigma\varepsilon_{\bar{K}_T})(\bar{w}^{\sigma\frac{T}{\mu}}-1)}$, where $0 < \alpha < 1$. Furthermore, $\frac{\varepsilon_{\bar{K}_T}}{T} - (1-\alpha)\frac{\ln\bar{w}}{\mu} = 0$ if and only if

$$\begin{aligned}
\frac{\sigma\varepsilon_{\bar{K}_T}}{(1-\sigma\varepsilon_{\bar{K}_T})(\bar{w}^{\sigma\frac{T}{\mu}}-1)}\frac{T}{\mu} - \frac{\varepsilon_{\bar{K}_T}}{\ln\bar{w}} &= 0 \\
\iff \frac{\varepsilon_{\bar{K}_T}}{\ln\bar{w}}\frac{\sigma\frac{T}{\mu}\ln\bar{w} - (1-\sigma\varepsilon_{\bar{K}_T})(\bar{w}^{\sigma\frac{T}{\mu}}-1)}{(1-\sigma\varepsilon_{\bar{K}_T})(\bar{w}^{\sigma\frac{T}{\mu}}-1)} &= 0
\end{aligned}$$

which holds as $1-\sigma\varepsilon_{\bar{K}_T} = \frac{\sigma\frac{T}{\mu}\ln\bar{w}}{\bar{w}^{\sigma\frac{T}{\mu}}-1}$. Consequently, $\frac{\partial\phi}{\partial T} > 0$ since $\frac{d\bar{w}}{dT} > 0$.

Proof of total labor income increase:

With the definition of $\varepsilon_{\bar{K}_T}$ and rearranging, the low-skilled wage (2.17) can be rewritten as $w_L = \Gamma T^{\kappa-\frac{1}{\sigma}}(\ln\bar{w})^{-\frac{1}{\sigma}}\left(1-\bar{w}^{-\sigma\frac{T}{\mu}}\right)^{\frac{1}{\sigma}}(L^s+\bar{w}H^s)^{\frac{1-\beta}{\beta}}$ where $\Gamma = \beta\left(\frac{1-\beta}{f}\right)^{\frac{1-\beta}{\beta}}\left(\frac{\mu}{\sigma}\right)^{\frac{1}{\sigma}}$. Plugging this into total labor income ($A = w_L L^s + w_H H^s$) results in $A = \Gamma T^{\kappa-\frac{1}{\sigma}}(\ln\bar{w})^{-\frac{1}{\sigma}}\left(1-\bar{w}^{-\sigma\frac{T}{\mu}}\right)^{\frac{1}{\sigma}}(L^s+\bar{w}H^s)^{\frac{1}{\beta}}$. The first derivative with respect to T reads as

$$\frac{\partial A}{\partial T} = A\left[\frac{\kappa-\frac{1}{\sigma}}{T}-\frac{\frac{d\bar{w}}{dT}}{\sigma\bar{w}\ln\bar{w}}+\frac{\bar{w}^{-\sigma\frac{T}{\mu}}}{1-\bar{w}^{-\sigma\frac{T}{\mu}}}\left(\frac{T}{\mu\bar{w}}\frac{d\bar{w}}{dT}+\frac{\ln\bar{w}}{\mu}\right)+\frac{\frac{H^s}{\beta}\frac{d\bar{w}}{dT}}{L^s+\bar{w}H^s}\right]$$
$$= A\left[\frac{\kappa-\frac{1}{\sigma}}{T}-\frac{\frac{d\bar{w}}{dT}}{\sigma\bar{w}\ln\bar{w}}+\frac{\frac{T}{\mu}\ln\bar{w}}{\bar{w}^{\sigma\frac{T}{\mu}}-1}\left(\frac{\frac{d\bar{w}}{dT}}{\bar{w}\ln\bar{w}}+\frac{1}{T}\right)+\frac{\frac{H^s}{\beta}\frac{d\bar{w}}{dT}}{L^s+\bar{w}H^s}\right]$$
$$= A\left[\frac{1}{T}\left(\underbrace{\frac{\frac{T}{\mu}\ln\bar{w}}{\bar{w}^{\sigma\frac{T}{\mu}}-1}-\frac{1}{\sigma}}_{=-\varepsilon_{\bar{K}_T}}+\kappa\right)+\frac{\frac{d\bar{w}}{dT}}{\bar{w}\ln\bar{w}}\left(\underbrace{\frac{\frac{T}{\mu}\ln\bar{w}}{\bar{w}^{\sigma\frac{T}{\mu}}-1}-\frac{1}{\sigma}}_{=-\varepsilon_{\bar{K}_T}}\right)+\frac{\frac{H^s}{\beta}\frac{d\bar{w}}{dT}}{L^s+\bar{w}H^s}\right]$$
$$= A\left[\frac{1}{T}\left(\kappa-\varepsilon_{\bar{K}_T}\right)+\frac{\frac{d\bar{w}}{dT}}{\bar{w}}\left(\frac{\frac{1}{\beta}}{\frac{L^s}{\bar{w}H^s}+1}-\frac{\varepsilon_{\bar{K}_T}}{\ln\bar{w}}\right)\right]. \tag{A2.14}$$

The skill premium equation (2.18) can be rearranged to $\frac{L^s}{\bar{w}H^s}=\frac{\frac{\ln\bar{w}}{\beta}-\varepsilon_{\bar{K}_T}}{\varepsilon_{\bar{K}_T}}$ which implies that

$$\frac{\partial A}{\partial T}=A\left[\frac{1}{T}\left(\kappa-\varepsilon_{\bar{K}_T}\right)+\frac{\frac{d\bar{w}}{dT}}{\bar{w}}\left(\frac{1}{\beta}\frac{\varepsilon_{\bar{K}_T}}{\frac{\ln\bar{w}}{\beta}}-\frac{\varepsilon_{\bar{K}_T}}{\ln\bar{w}}\right)\right]=A\frac{\kappa-\varepsilon_{\bar{K}_T}}{T}>0$$

since $\kappa>\varepsilon_{\bar{K}_T}$. This holds if and only if firms are technologically restricted. Otherwise, $\kappa=\varepsilon_{\bar{K}_T}$ and $\frac{\partial A}{\partial T}=0$. Moreover, $P_I\equiv\left(\int_0^M p_i^{-\frac{\beta}{1-\beta}}di\right)^{-\frac{1-\beta}{\beta}}$ is normalized to one, involving $Y_i=\left(\frac{p_i}{P_I}\right)^{-\frac{1}{1-\beta}}\frac{A}{P_I}=p_i^{-\frac{1}{1-\beta}}A$. This is plugged into the utility function of the representative household ($u=\left(\int_0^M Y_i^\beta di\right)^{\frac{1}{\beta}}$) that also constitutes a measure of economy's welfare. Straight forward manipulations imply $u=A$ and, consequently, $\frac{\partial A}{\partial T}>0 \iff \frac{\partial u}{\partial T}>0$.

2.7.6 Proofs for Heterogeneous firms

Proof of Proposition 2.6

Proof of an increase in the skill premium and in the technology gap:

The proof applies the concept of implicit differentiation. First, rewriting the skill premium equation (2.20), using (2.10) and setting $N_h=T$ (i.e. only h-firms are restricted), results in

$$J(\bar{w},T)\equiv\frac{T^{\kappa_h}}{N_l^{\kappa_l}}\bar{w}^{-\frac{T-N_l}{\mu}}\left(\frac{1-\sigma\kappa_l}{1-\sigma\varepsilon_{\bar{K}_T}}\right)^{\frac{1}{\sigma}}-\left(\frac{f_h}{f_l}\right)^{\frac{1-\beta}{\beta}}=0.$$

Second, the derivative of $J(\bar{w},T)$ with respect to T, holding $\bar{w}$ constant, is calculated:

$$\frac{\partial J(\bar{w},T)}{\partial T}=\frac{T^{\kappa_h}}{N_l^{\kappa_l}}\bar{w}^{-\frac{T-N_l}{\mu}}\left(\frac{1-\sigma\kappa_l}{1-\sigma\varepsilon_{\bar{K}_T}}\right)^{\frac{1}{\sigma}}\left[\frac{\kappa_h}{T}-\frac{\ln\bar{w}}{\mu}+(1-\sigma\varepsilon_{\bar{K}_T})^{-1}\frac{\partial\varepsilon_{\bar{K}_T}}{\partial T}\right].$$

Using (A2.6) and manipulating leads to

$$\frac{\partial J(\bar{w},T)}{\partial T}=\frac{T^{\kappa_h}}{N_l^{\kappa_l}}\bar{w}^{-\frac{T-N_l}{\mu}}\left(\frac{1-\sigma\kappa_l}{1-\sigma\varepsilon_{\bar{K}_T}}\right)^{\frac{1}{\sigma}}\frac{1}{T}\left[\kappa_h-\frac{1}{\sigma}+\left(\bar{w}^{\sigma\frac{T}{\mu}}-1\right)\left(\frac{1}{\sigma}-\varepsilon_{\bar{K}_T}\right)+\left(\frac{1}{\sigma}-\varepsilon_{\bar{K}_T}\right)-\frac{T}{\mu}\ln\bar{w}\right]$$

which can be, factoring out $\bar{w}^{\sigma\frac{T}{\mu}}-1$ and using $\varepsilon_{\bar{K}_T}=\frac{1}{\sigma}-\frac{\frac{T}{\mu}\ln\bar{w}}{\bar{w}^{\sigma\frac{T}{\mu}}-1}$, further simplified to

$$\frac{\partial J(\bar{w},T)}{\partial T}=\frac{T^{\kappa_h}}{N_l^{\kappa_l}}\bar{w}^{-\frac{T-N_l}{\mu}}\left(\frac{1-\sigma\kappa_l}{1-\sigma\varepsilon_{\bar{K}_T}}\right)^{\frac{1}{\sigma}}\frac{\kappa_h-\varepsilon_{\bar{K}_T}}{T}>0$$

since $\varepsilon_{\bar{K}_T}<\kappa_h$ as long as the technology choice of the h-firm is restricted. Third, the derivative of $J(\bar{w},T)$ with respect to $\bar{w}$, is calculated:

$$\frac{\partial J(\bar{w},T)}{\partial\bar{w}}=\frac{T^{\kappa_h}}{N_l^{\kappa_l}}\bar{w}^{-\frac{T-N_l}{\mu}}\left(\frac{1-\sigma\kappa_l}{1-\sigma\varepsilon_{\bar{K}_T}}\right)^{\frac{1}{\sigma}}\left[-\frac{\kappa_l}{N_l}\frac{dN_l}{d\bar{w}}+\frac{-T+N_l}{\bar{w}\mu}+\frac{\ln\bar{w}}{\mu}\frac{dN_l}{d\bar{w}}+(1-\sigma\varepsilon_{\bar{K}_T})^{-1}\frac{\partial\varepsilon_{\bar{K}_T}}{\partial\bar{w}}\right].$$

Using $\frac{dN_l}{d\bar{w}}$ from *Proposition 2.1* and (A2.7), the above derivative becomes

$$\frac{\partial J(\bar{w},T)}{\partial\bar{w}}=$$
$$=\frac{T^{\kappa_h}}{N_l^{\kappa_l}}\bar{w}^{-\frac{T-N_l}{\mu}}\left(\frac{1-\sigma\kappa_l}{1-\sigma\varepsilon_{\bar{K}_T}}\right)^{\frac{1}{\sigma}}\frac{1}{\bar{w}\ln\bar{w}}\left[\kappa_l-\frac{1}{\sigma}+\left(\bar{w}^{\sigma\frac{T}{\mu}}-1\right)\left(\frac{1}{\sigma}-\varepsilon_{\bar{K}_T}\right)+\left(\frac{1}{\sigma}-\varepsilon_{\bar{K}_T}\right)-\frac{T}{\mu}\ln\bar{w}\right]$$

which can be, factoring out $\bar{w}^{\sigma\frac{T}{\mu}}-1$ and using $\varepsilon_{\bar{K}_T}=\frac{1}{\sigma}-\frac{\frac{T}{\mu}\ln\bar{w}}{\bar{w}^{\sigma\frac{T}{\mu}}-1}$, further simplified to

$$\frac{\partial J(\bar{w},T)}{\partial w}=\frac{T^{\kappa_h}}{N_l^{\kappa_l}}\bar{w}^{-\frac{T-N_l}{\mu}}\left(\frac{1-\sigma\kappa_l}{1-\sigma\varepsilon_{\bar{K}_T}}\right)^{\frac{1}{\sigma}}\frac{\kappa_l-\varepsilon_{\bar{K}_T}}{\bar{w}\ln\bar{w}}<0.$$

Here, $\varepsilon_{\bar{K}_T}>\kappa_l$ as otherwise the technology choice of the h-firm would not be restricted. As a consequence,

$$\frac{d\bar{w}}{dT}=-\frac{\frac{\partial J(\bar{w},T)}{\partial T}}{\frac{\partial J(\bar{w},T)}{\partial w}}=\frac{\bar{w}\ln\bar{w}}{T}\frac{\kappa_h-\varepsilon_{\bar{K}_T}}{\varepsilon_{\bar{K}_T}-\kappa_l}>0$$

and it holds that $\frac{\partial\left(\frac{T}{N_l}\right)}{\partial T} = \frac{\kappa_h-\kappa_l}{N_l(\varepsilon_{\bar{K}_T}-\kappa_l)} > 0$.

Proof that the productivity gap is constant:

From (2.10),

$$\phi_\Delta = \frac{T^{\kappa_h}}{N_l^{\kappa_l}}\bar{w}^{-\frac{T-N_l}{\mu}}\left(\frac{1-\sigma\kappa_l}{1-\sigma\varepsilon_{\bar{K}_T}}\right)^{\frac{1}{\sigma}}.$$

Taking the first derivative with respect to T leads to

$$\frac{\partial\phi_\Delta}{\partial T} = \phi_\Delta\left(\frac{\kappa_h}{T} - \frac{\kappa_l}{N_l}\frac{dN_l}{d\bar{w}}\frac{d\bar{w}}{dT} - \frac{1}{\bar{w}}\frac{T-N_l}{\mu}\frac{d\bar{w}}{dT} - \ln\bar{w}\left(\frac{1}{\mu} - \frac{1}{\mu}\frac{dN_l}{d\bar{w}}\frac{d\bar{w}}{dT}\right) + \frac{\frac{\partial\varepsilon_{\bar{K}_T}}{\partial T}}{1-\sigma\varepsilon_{\bar{K}_T}}\right).$$

Calculating the derivative of $\varepsilon_{\bar{K}_T}$ with respect to T *without* holding $\bar{w}$ constant implies

$$\frac{\partial\varepsilon_{\bar{K}_T}}{\partial T} = \left(\frac{T}{\mu\bar{w}}\frac{d\bar{w}}{dT} + \frac{\ln\bar{w}}{\mu}\right)\frac{(1-\sigma\varepsilon_{\bar{K}_T})\bar{w}^{\sigma\frac{T}{\mu}}-1}{\bar{w}^{\sigma\frac{T}{\mu}}-1}.$$

Using this, $\frac{d\bar{w}}{dT}$ from above, and $\frac{dN_l}{d\bar{w}}$ from *Proposition 2.1* results in:

$$\frac{\partial\phi_\Delta}{\partial T} = \phi_\Delta\left(\frac{\kappa_h}{T} - \frac{\kappa_l}{T}\frac{\kappa_h-\varepsilon_{\bar{K}_T}}{\varepsilon_{\bar{K}_T}-\kappa_l} - \frac{\ln\bar{w}}{\mu}\left(1+\frac{\kappa_h-\varepsilon_{\bar{K}_T}}{\varepsilon_{\bar{K}_T}-\kappa_l}\right) + \frac{\ln\bar{w}}{\mu}\frac{\left(\frac{\kappa_h-\varepsilon_{\bar{K}_T}}{\varepsilon_{\bar{K}_T}-\kappa_l}+1\right)\left((1-\sigma\varepsilon_{\bar{K}_T})\bar{w}^{\sigma\frac{T}{\mu}}-1\right)}{(1-\sigma\varepsilon_{\bar{K}_T})(\bar{w}^{\sigma\frac{T}{\mu}}-1)}\right).$$

Employing the definition of $\varepsilon_{\bar{K}_T}$ and rearranging directly implies $\frac{\partial\phi_\Delta}{\partial T} = 0$. Employing a different approach, the results of *Proposition 2.3* in combination with $d\bar{w}/dT$ show that

$$\frac{\partial\phi_\Delta}{\partial T} = \left.\frac{\partial\phi_\Delta}{\partial T}\right|_{\bar{w}=\text{const.}} + \frac{\partial\phi_\Delta}{\partial\bar{w}}\frac{d\bar{w}}{dT} = 0.$$

Proof of Proposition 2.7

Proof of $\forall\frac{f_h}{f_l} \leq \left(\frac{f_h}{f_l}\right)^*$, $M_h > 0$, $M_l = 0$:

Let's denote the largest $\frac{f_h}{f_l}$ that ensures $M_h > 0$, $M_l = 0$ by $\left(\frac{f_h}{f_l}\right)^*$. For any $\left(\frac{f_h}{f_l}\right)^* + \delta$, $(\delta > 0)$ l-firms enter and $M_h > 0$, $M_l > 0$. Thus $\forall\frac{f_h}{f_l} \leq \left(\frac{f_h}{f_l}\right)^*$,

$$M_l = \frac{(1-\beta)(\varepsilon_{\bar{K}_T}L^S - \bar{w}H^S(\frac{\ln(\bar{w})}{\beta}-\varepsilon_{\bar{K}_T}))}{f_l(\varepsilon_{\bar{K}_T}-\kappa_l)} = 0 \iff \bar{w}H^s = \frac{\varepsilon_{\bar{K}_T}L^s}{\frac{\ln\bar{w}}{\beta}-\varepsilon_{\bar{K}_T}}$$

where the last equation determines the skill premium in an economy populated only by h-firms.

Proof of $\forall \frac{f_h}{f_l} \geq \left(\frac{f_h}{f_l}\right)^{**}$, $M_h = 0$, $M_l > 0$:

Let's denote the smallest $\frac{f_h}{f_l}$ that ensures $M_h = 0$, $M_l > 0$ by $\left(\frac{f_h}{f_l}\right)^{**}$. For any $\left(\frac{f_h}{f_l}\right)^{**} - \delta$, $(\delta > 0)$ h-firms enter and $M_h > 0$, $M_l > 0$. Thus $\forall \frac{f_h}{f_l} \geq \left(\frac{f_h}{f_l}\right)^{**}$,

$$M_h = \frac{(1-\beta)(\bar{w}H^S(\frac{\ln(\bar{w})}{\beta} - \kappa_l) - \kappa_l L^S)}{f_h(\varepsilon_{\bar{K}_T} - \kappa_l)} = 0 \iff \bar{w}H^s = \frac{\kappa_l L^s}{\frac{\ln \bar{w}}{\beta} - \kappa_l}$$

where the last equation determines the skill premium in an economy populated by κ_l-firms.

Proof of the existence of the interval $\left(\left(\frac{f_h}{f_l}\right)^{*}, \left(\frac{f_h}{f_l}\right)^{**}\right)$:

From *Proposition 2.3*, $\partial\phi_\Delta/\partial\bar{w} < 0$. Consequently, the right hand side of (2.20), $\frac{f_h}{f_l}$, can only be decreased if and only if the skill premium is increased. Thus, $\left(\frac{f_h}{f_l}\right)^{*} < \left(\frac{f_h}{f_l}\right)^{**} \iff \bar{w}^* > \bar{w}^{**}$. $M_h = 0$ implies a closed economy populated by l-firms and $M_l = 0$ one by h-firms. As *Proposition 2.5* states that $d\bar{w}/d\kappa > 0$, $\bar{w}^* > \bar{w}^{**}$ and, consequently, $\left(\frac{f_h}{f_l}\right)^{*} < \left(\frac{f_h}{f_l}\right)^{**}$. This implies the existence of the interval $\left(\left(\frac{f_h}{f_l}\right)^{*}, \left(\frac{f_h}{f_l}\right)^{**}\right)$. Note that whether h-firms are restricted or not by T is not important for the existence of such an interval. Nevertheless, as T reduces the gains from technology for potential h-firms, it lowers $\left(\frac{f_h}{f_l}\right)^{**}$.

Proof of Proposition 2.8

Proof of an increase in welfare

Following the reasoning in the proof of *Proposition 2.5*, a country's welfare increases if A rises and, moreover, the low-skilled wage (2.24) can be rewritten (with the definition of $\varepsilon_{\bar{K}_T}$) as $w_L = \Gamma_h T^{\kappa_h - \frac{1}{\sigma}} (\ln \bar{w})^{-\frac{1}{\sigma}} \left(1 - \bar{w}^{-\sigma\frac{T}{\mu}}\right)^{\frac{1}{\sigma}} (L^s + \bar{w}H^s)^{\frac{1-\beta}{\beta}}$ where $\Gamma_h = \beta\left(\frac{1-\beta}{f_h}\right)^{\frac{1-\beta}{\beta}} \left(\frac{\mu}{\sigma}\right)^{\frac{1}{\sigma}}$. Plugging this into total labor income ($A = w_L L^s + w_H H^s$) results in $A = \Gamma_h T^{\kappa_h - \frac{1}{\sigma}} (\ln \bar{w})^{-\frac{1}{\sigma}} \left(1 - \bar{w}^{-\sigma\frac{T}{\mu}}\right)^{\frac{1}{\sigma}} (L^s + \bar{w}H^s)^{\frac{1}{\beta}}$. Following again the reasoning in the proof of *Proposition 2.5* (in particular dA/dT (A2.14)) results in

$$\frac{\partial A}{\partial T} = A\left[\frac{1}{T}\left(\kappa_h - \varepsilon_{\bar{K}_T}\right) + \frac{\frac{d\bar{w}}{dT}}{\bar{w}}\left(\frac{\frac{1}{\beta}}{\frac{L^s}{\bar{w}H^s} + 1} - \frac{\varepsilon_{\bar{K}_T}}{\ln \bar{w}}\right)\right] = \frac{A}{T}\frac{\kappa_h - \varepsilon_{\bar{K}_T}}{\varepsilon_{\bar{K}_T} - \kappa_l}\left[\frac{\frac{\ln \bar{w}}{\beta}}{\frac{L^s}{\bar{w}H^s} + 1} - \kappa_l\right]$$

where I employ $d\bar{w}/dT$ (see *Proposition 2.6*). As a consequence,

$$\frac{\partial A}{\partial T} > 0 \iff \frac{\frac{\ln \bar{w}}{\beta}}{\frac{L^s}{\bar{w}H^s} + 1} > \kappa_l \iff \bar{w}H^s\left(\frac{\ln \bar{w}}{\beta} - \kappa_l\right) > \kappa_l L^s.$$

Since the latter inequality holds if high productivity firms enter the economy (see the proof of *Proposition 2.7*), $\frac{\partial A}{\partial T} > 0$ is true in the heterogeneous firms equilibrium.

Proof of the derivative of w_L with respect to T

The first derivative of the low-skilled wage (2.24) with respect to T implies

$$\frac{\partial w_L}{\partial T} = w_L\left(\frac{\kappa_h}{T} - \frac{T}{\mu\bar{w}}\frac{d\bar{w}}{dT} - \frac{\ln \bar{w}}{\mu} + \frac{\frac{\partial \varepsilon_{\bar{K}_T}}{\partial T}}{1 - \sigma\varepsilon_{\bar{K}_T}} + \frac{1-\beta}{\beta}\frac{H^s \frac{d\bar{w}}{dT}}{L^s + \bar{w}H^s}\right).$$

Plugging in $\frac{\partial \varepsilon_{\bar{K}_T}}{\partial T}$ from *Proof 2.7.6* and $\frac{d\bar{w}}{T}$ from *Propositon 2.6* and subsequent manipulating directly leads to $\frac{\partial w_L}{\partial T} = \frac{w_L}{T}\frac{\kappa_h - \varepsilon_{\bar{K}_T}}{\varepsilon_{\bar{K}_T} - \kappa_l}\left(\frac{1-\beta}{\beta}\frac{\bar{w}H^s}{L^s + \bar{w}H^s}\ln \bar{w} - \kappa_l\right)$.

Proof of the derivative of w_H with respect to T

Since $w_H = w_L\bar{w}$ the derivative of w_H with respect to T is easily calculated as

$$\begin{aligned}
\frac{\partial w_H}{\partial T} &= \frac{\partial \bar{w}}{\partial T}w_L + \frac{\partial w_L}{\partial T}\bar{w} \\
&= \frac{w_H}{T(L^s + \bar{w}H^s)}\frac{\kappa_h - \varepsilon_{\bar{K}_T}}{\varepsilon_{\bar{K}_T} - \kappa_l}\left(L^s \ln \bar{w} + \bar{w}H^s\left(\frac{\ln \bar{w}}{\beta} - \kappa_l\right) - \kappa_l L^s\right) > 0
\end{aligned}$$

where $\bar{w}H^s\left(\frac{\ln \bar{w}}{\beta} - \kappa_l\right) - \kappa_l L^s > 0$ if $M_h > 0$.

Chapter 3

The Impact of Intermediates' Value Added on the Structure of Global Production Processes[0]

3.1 Introduction

Most processes in manufacturing industries consists of a large number of intermediate stages, a phenomenon already described in Smith (1776)'s famous pin factory example. Today, production processes not only imply that workers specialize within a plant, but also involve specialization of countries in intermediate stages of a good's production, referred to as vertical specialization by Hummels et al. (2001). Moreover, global supply chains exhibit a great variety in the sequence of intermediate product flows and organizational structures. Since production of large passenger airplanes, i.e. Boeing's 787 Dreamliner and Airbus' A380, involves one of the most complex production processes it has attracted attention in the recent literature on the organization of global value chains (Antràs and Chor, 2011). Moreover, a comparison of Boeing's and Airbus' flows of intermediate products reveals important differences in the structure of production processes.

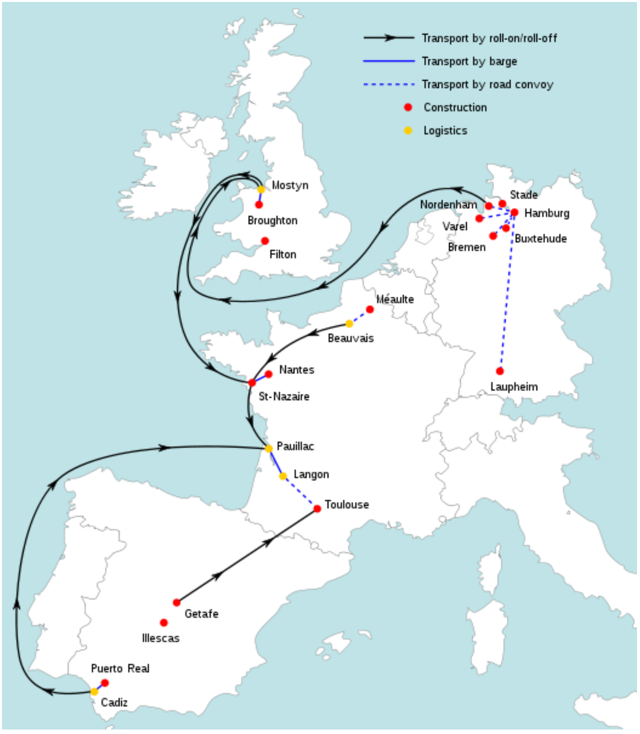
Boeing procures almost 70%[1] of 787's parts from external and/or foreign suppliers and

[0] This chapter is based on joint work with Carsten Eckel.

[1] See e.g. Newhouse (2008).

is doing final assembly in its main factory in Everett, Washington. Completion of a particular intermediate stage, e.g. the construction of a wing or a large part of the fuselage, is carried out by an external supplier, independently of other steps. The structure of Boeing's airplane manufacturing exhibits, hence, parallel processes which are integrated in the overall sequence of production studied in more detail by Antràs and Chor (2011). In contrast, production of the A380 involves subsequent shipping of the airplane's semifin-

Figure 3.1: Itinéraire à Grand Gabarit



Structure of the Production Process of Airbus' A380. Intermediate parts are shipped and processed following the Itinéraire à Grand Gabarit.

ished goods throughout Europe while they are consecutively being upgraded (see *Figure 3.1*[2]). In brief, the production process involves first that the front and rear sections of the fuselage are shipped from Hamburg to Saint-Nazaire, France. There, sections like the nose are added and the resulting bigger pieces are shipped to Toulouse where the plane is assembled. However, for being painted and furnished, the almost finished plane is flown to Hamburg Finkenwerder Airport[3]. As a consequence, A380's production process is of

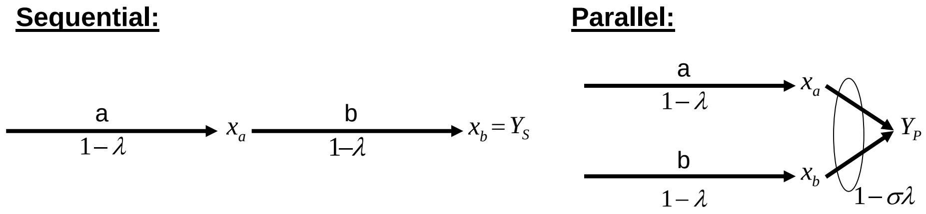
[2]Source: http://en.wikipedia.org/wiki/File:Transport_A380_en.svg, December 2011

[3]In fact, these stages account only for a fraction of the shipping process which is labeled 'Itinéraire à Grand Gabarit' and include a more or less subsequent shipping throughout Europe.

a more sequential nature than that of Boeing's Dreamliner. The example of the aviation industry is in line with the more general observation that production structures can be characterized by the kind of alignment of two different intermediate production stages: sequential versus parallel[4].

Our main contribution is to develop a simple theory of endogenous production structures that provides a more detailed understanding of firms' decisions to choose a rather sequential or a more parallel nature of their production processes. *Figure 3.2* illustrates a firm's

Figure 3.2: Sequential Versus Parallel Structures of Production



choice on the structure of production. First, intermediate stage x_a is carried out using a units of labor and facing a probability of making mistakes during the process of λ[5]. After having completed the first step, the intermediate is either shipped and processed in another plant or combined with the second intermediate where both approaches yield the final product, Y_S, respectively, Y_P. Here, and throughout this chapter, S indicates sequential and P parallel production. In the first (sequential production) case, components are added in a second intermediate stage x_b which requires b units of labor and where the almost completed product faces a risk of destruction during the intermediate stage of λ. In the second (parallel production) case, the second intermediate step x_b is completed simultaneously to the first, using b units of labor and with a risk of being destroyed during the process of λ. The final product is assembled subsequently without any labor costs, but with a probability of failure during assembly of $\sigma\lambda$, where $0 < \sigma < 1$.

Since labor is the only factor of production, a and b constitute the respective value added of each stage. Whether a firm chooses optimally a sequential or parallel production structure

[4]See e.g. p. 680 and 681 in Fabozzi et al. (2008) for a description of different product flows.

[5]Although we denote λ as the probability of making mistakes, i.e. the risk of destroying the product at this stage, it represents also a measure of general productivity.

is determined by the trade-off between the potential loss in sequential structure's second step and the risk of losing both intermediates during parallel's assembly process. The greater the first step's relative value added ($\frac{a}{b}$), the more inclined is a firm to choose the parallel structure to avoid complete loss in the second step within a sequential production structure. A higher probability of making mistakes reduces the respective threshold of relative value added. In contrast, a greater probability of complete loss during assembly favors the adoption of sequential production processes.

Embedding the firm-level choice on optimal production structures into a framework of perfect competition in closed economy shows that country differences in failure rates may lead to disparities in the organization of production processes across countries. An economy where firms face higher probabilities of making mistakes in production chooses a parallel production process for lower relative value added. Countries which are less prone to mistakes keep a sequential organization for higher relative value added. This result holds irrespective of country-level labor endowments.

In open economy, countries differ with respect to their labor endowments and the probability of making mistakes. Perfect competition on all markets results in an efficient global production structure. A sequential global value chain emerges if relative value added of intermediates does not surpass a threshold. Countries of lower failure rates specialize in later stages of the global production process implying Ricardian comparative advantage among nations (Ricardo, 1817). However, as in Ricardo's approach, only the country that completely specializes gains in terms of welfare. If relative value added is relatively great compared to the failure rate, the potential loss of the almost finished product at the final stage outweighs welfare gains from Ricardian specialization. In this case, production processes are parallel and the specialization of countries on a single intermediate stage is redundant. However, the combination of country-specific destruction risks during assembly and no labor costs of the latter imply that assembly is always done in countries with low failure rates.

The economic literature explains wage differentials across countries in the presence of trade largely by differences in country-level and factor-specific productivities. See Trefler (1993) for an early and Maskus and Nishioka (2009) for a recent contribution of how the factor-price equalization theorem can be reconciled with factor price disparities by considering country- and factor-level differences in technologies and productivities. In this vein, the efficiency of a country's workforce depends on the nature of (global) production structures. In our model, we correct wages for differences in country-level productivities that result from specific production structures. We show that the implied efficient wages equalize across countries.

The economic analysis of global value chains is at the heart of a vivid discussion. Grossman and Rossi-Hansberg (2008) build a model where reducing offshoring costs implies productivity and welfare gains for all factors. In later work (Grossman and Rossi-Hansberg, 2011), they show that tasks with higher offshoring costs are produced in countries with higher wages and greater aggregated output. Antràs and Chor (2011) analyze the optimal extend of integration along the value chain. Our study is most closely related to Costinot et al. (2011)[6]'s who focus on the impact of country-level differences in the probability of making mistakes on the structure of global production processes. In their model, a sequential global value chain emerges endogenously where less productive countries concentrate on earlier intermediate production stages and more productive economies on later steps. Our model replicates this sequential production structure across countries if relative value added of intermediates does not surpass a threshold. However, organizational structures in Costinot et al. (2011) are exogenously determined to be either sequential or parallel such that there exists no endogenous choice on the shape of production processes. We add to the literature an endogenous firm-level choice on the structure of production that depends on a trade-off between relative value added at risk and the probability of making mistakes. Furthermore, Costinot et al. (2011) implicitly assume that relative value added of intermediate production stages ($\frac{a}{b}$) is necessarily one. However, we show that different values of $\frac{a}{b}$ may have a crucial impact on the structure of local and global value chains.

This chapter is organized as follows. *Section 3.2* introduces the firm-level decision on the optimal structure of the production process. This is embedded into a perfect competition framework in closed economy in *Section 3.3*. The impacts of firm-level choices on the organization of the global value chain are analyzed in *Section 3.4*. *Section 3.5* concludes.

[6]They build their model on work by Sobel (1992) and Kremer (1993) who introduced production that is sequential and subject to mistakes.

3.2 The Production Process on the Firm Level

Each firm produces the final good Y with labor only, taking wages and prices as given. Production requires two intermediate stages and, depending on the structure of the process (see *Figure 3.2*), subsequent assembling. Abstracting from any contracting issues[7] we stay agnostic with respect to the ownership structure.

3.2.1 Optimal Firm-Level Production Structure

The intermediate product x_a is manufactured with probability $1-\lambda$ using a units of labor implying that $\frac{a}{1-\lambda}$ units of labor are required to produce one unit of x_a. Similarly, $\frac{b}{1-\lambda}$ units of labor are needed to complete one unit of intermediate input x_b. While the labor requirements of the two intermediate stages are identical across production structures the process differs with respect to the input x_b. Within a sequential structure, one unit of intermediate product x_a is processed into the final product Y_S using b units of labor and exposing the value added of the first *and* second stage to a loss that occurs with probability λ. In contrast, if a firm chooses a parallel production structure intermediates x_a and x_b are produced within independent processes with the respective unit labor requirements of $\frac{a}{1-\lambda}$ and $\frac{b}{1-\lambda}$. Subsequently, they have to be assembled to the final product. Although we assume that labor input of assembly is negligible compared to intermediate stages (and therefore set labor requirements to zero), the final product will only be accomplished with probability $1-\sigma\lambda$. We impose $0 < \sigma < 1$, as assembly involves usually less far-reaching activities than actual production. Nevertheless, the final product will be identical across production structures.

Since we assume perfect competition on output markets, a firm's profit maximization implies setting prices equal to marginal cost. Furthermore, a firm's linear cost structure involves that marginal cost equal minimum unit cost to produce the final good Y. Since either production process would deliver an identical final output, a firm's decision is reduced to choose between a sequential or parallel production process. The implied

[7] See e.g. Antràs and Chor (2011).

minimum unit cost functions are

$$k_S = \frac{\frac{aw}{1-\lambda} + bw}{1-\lambda} \tag{3.1}$$

$$k_P = \frac{\frac{aw}{1-\lambda} + \frac{bw}{1-\lambda}}{1-\sigma\lambda} \tag{3.2}$$

where k_S are minimum unit cost of sequential and k_P minimum unit cost of parallel production. An optimal choice involves to minimize costs, i.e. to compare minimum unit cost of a parallel or sequential production process: $k_S \gtrless k_P$.

Proposition 3.1 *The higher the relative value added of the first intermediate production step the more inclined is a firm to choose parallel production. A smaller probability of making mistakes during intermediate stages and a higher risk of failures during assembling imply that firms rather choose sequential processes.*

The proof simply involves comparing minimum unit costs (3.1) and (3.2). As a result, the firm chooses a parallel production process if and only if $k_S > k_P$ implying that

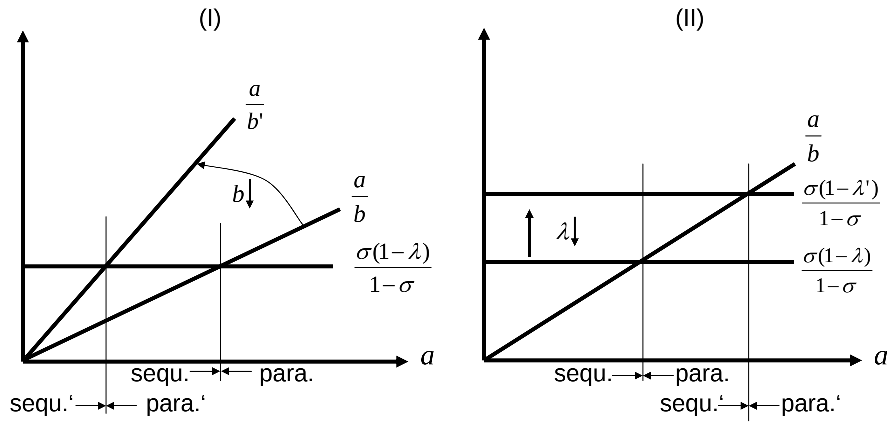
$$\frac{a}{b} > \frac{\sigma(1-\lambda)}{1-\sigma}. \tag{3.3}$$

Otherwise, it chooses a sequential structure. In the case of $\frac{a}{b} = \frac{\sigma(1-\lambda)}{1-\sigma}$, the firm is indifferent between a sequential and a parallel production structure. Since this case does not add insight to our analysis, we abstract from it throughout this study[8]. *Figure 3.3* illustrates the fundamental trade-offs driving a firm's choices[9]. A decrease in the value added within the second intermediate stage (i.e. a lower labor requirement b) in graph *(I)* induces an increase of the relative value added of the first step, $\frac{a}{b}$. Accordingly, the range for which sequential production is optimal, becomes smaller. In *(I)*, this implies a shift of the threshold level of value added towards lower values of a. Graph *(II)* illustrates the impact of a lower probability of making mistakes, $\lambda' < \lambda$, involving a higher threshold value of failure rates $\frac{\sigma(1-\lambda')}{1-\sigma} > \frac{\sigma(1-\lambda)}{1-\sigma}$. As a consequence, a sequential production process is optimal for higher relative value added and the respective threshold is shifted towards

[8] The most simple remedy to an exclusion would be to assume that whenever a firm is indifferent it chooses a parallel (or, equivalently, a sequential) production process.

[9] Note that we do comparative statics with respect to λ and b. The choice of a instead of b would not alter the results since the effects are driven by relative value added.

Figure 3.3: Firm-Level Comparative Statics



Impact of higher relative value added and a lower probability of making mistakes on a firm's choice.

higher labor requirements a. Or, although the failure rate of assembling decreases proportionally to the intermediates' probability of making mistakes, its absolute decrease is smaller since $\lambda - \lambda' > \sigma\lambda - \sigma\lambda' \iff 1 > \sigma$. Consequently, the risk of losing products during assembling outweighs the risk of destruction during the second intermediate step for higher relative value added $\frac{a}{b}$, implying a higher threshold value of a since b is assumed to be constant in this case.

3.2.2 An Application to the Aviation Industry

We pick up our example of the aviation industry from the introduction to illustrate firms' endogenous choices on the structure of production processes. In the introduction, we established that Boeing's production of the 787 (Dreamliner) exhibits a more sequential structure than the manufacturing of Airbus' A380. This directly relates to our firm-level analysis of optimal production processes from above. It implies that either Boeing's production structure involves lower relative value added within later intermediate stages or that it is exposed to higher failure rates within intermediates' production.

Since the 787 and the A380 are rather close substitutes[10], the relative value added within the production of comparable parts (e.g. wings, engine) should not differ significantly.

[10]This is true from our global perspective. We are aware that both aircraft differ with e.g. respect to the maximum of passenger numbers and, though less, range (787-9: 290, 15700km; A380-800: 853, 15200 km).

However, the economic literature tends to acknowledge that firms are more able to reduce mistakes in production processes if their organizational structures are more integrated[11]. Moreover, while Airbus adds about 75%[12] of the work done in the manufacturing of the A380, Boeing contributes only 30% in the manufacture of the 787. Thus, we can sensibly assume that the probability of making mistakes in the Dreamliner's intermediate production stages is higher than that within the intermediate steps in the process of making A380s. Or, Boeing's tendency to outsource large chunks of 787's production requires to structure production in a rather parallel manner as it faces higher failure rates from external suppliers. In contrast, Airbus opts for a more sequential structure of its production process since its more integrated value chain implies lower probabilities of making mistakes in intermediated stages.

Note that we abstract in this example from different failure rates across countries since assembly as well as intermediate production stages are carried out to a large extend in countries with a similar level of productivity, i.e. similar probabilities of making mistakes. Here, the ownership structure[13], and not the location of plants within different countries, implies disparities in the probability of making mistakes.

3.3 Equilibrium in Closed Economy

We assume perfectly competitive factor and output markets. As a consequence, it is sufficient to analyze a representative firm's choice to determine a country's structure of production processes. In this vein, firm-level decisions on the optimal production structure are embedded in a general equilibrium in closed economy. In particular, the representative firm produces a final good exclusively with labor and a representative consumer supplies labor inelastically, spending the earnings to finance consumption. However, the firm's choice on the structure of the production process has direct repercussions on labor demand

[11] Antràs and Chor (2011) describe Boeing's subsequent acquisition of its problematic supplier Vought Aircraft Industries as an example where integration reduces mistakes that hamper the supply chain.

[12] While Boeing has asked its partnering suppliers to carry all non-recurring costs in exchange for intellectual property rights, Airbus shares only 25% and keeps the rights on core technologies (Horng, 2007).

[13] We are aware that the ownership structure may itself be endogenous. However, within the context of our analysis different ownership structures have no impact on the optimal decision of production processes since we abstract from contracting problems.

and, thus, wages. Since firm's decisions depend on the fact whether (3.3) holds we have to distinguish equilibrium results accordingly.

3.3.1 Equilibrium given a Parallel Production Process

Here, we assume that $\frac{a}{b} > \frac{\sigma(1-\lambda)}{1-\sigma}$. Consequently, the parallel organization of production maximizes profits[14] and output. Equilibrium quantities of intermediate stages are required to be equal in production, $x_{c,a,P} = x_{c,b,P}$, where c denotes variables in closed economy. Analogously, this involves equal effective labor demands across intermediate steps:

$$\frac{L_{c,a,P}}{a} = \frac{L_{c,b,P}}{b}. \tag{3.4}$$

where $L_{c,a,P}$ ($L_{c,b,P}$) denotes labor demand for the production of intermediate $x_{c,a,P}$ ($x_{c,b,P}$). Moreover, the parallel production structure represents a production function à la Leontief (1941) since (3.4) requires a fixed factor input relation. Nevertheless, at this stage our analysis is not hindered since both intermediate steps are done by using the same type of factor input, labor.

Aggregating labor demands of intermediate production stages implies labor market clearing, $L = L_{c,a,P} + L_{c,b,P}$, where L denotes a country's labor endowment. Plugging the Leontief-style factor input relation from (3.4) into the former condition results in $L_{c,a,P} = \frac{aL}{a+b}$ which involves the production of $x_{c,a,P} = \frac{(1-\lambda)L}{a+b}$ since $\frac{1-\lambda}{a}$ units of labor are required to produce one unit of x_a. However, as assembly is prone to make mistakes with a probability of $\sigma\lambda$ aggregate production of the economy amounts to

$$Y_{c,P} = \frac{(1-\lambda)(1-\sigma\lambda)L}{a+b}. \tag{3.5}$$

Since the final good is sold on a perfectly competitive market its price p equals marginal, respectively minimum unit costs: $p = k_{c,P} = w_{c,P}\frac{a+b}{(1-\lambda)(1-\sigma\lambda)}$. The price of the final good is normalized to one ($p \equiv 1$) and labor receives the wage

$$w_{c,P} = \frac{(1-\lambda)(1-\sigma\lambda)}{a+b}. \tag{3.6}$$

[14] Note that profits are zero since there is perfect competition.

Note that perfect competition on output and factor markets involves $Y_{c,P} = w_{c,P}L$ and, consequently, the marginal productivity of labor equals the wage rate. Productivity of labor hence directly relates not only to intermediate-specific input requirements (a and b), but also to country-level failure rates (λ and $\sigma\lambda$) that imply country-level productivities.

Proposition 3.2 *When parallel production is optimal, the wage level as well as the aggregate output decrease in the probability of making mistakes during intermediate stages and assembly. Furthermore, higher labor input requirements imply lower wages and less final goods.*

The probability of making mistakes represents a measure of a country's productivity[15]. Necessarily, aggregated output is lower for lower levels of productivity. Or, more illustrative, if a higher rate of intermediates is destroyed within the production process less final products are accomplished. Moreover, the marginal productivity of labor decreases and, hence, the wage rate. In the same vein, higher labor input requirements decrease labor's marginal productivity and also its wage level. Furthermore, aggregated output is decreased as less intermediate inputs are completed.

3.3.2 Equilibrium given a Sequential Production Process

Within this section, we assume that $\frac{a}{b} < \frac{\sigma(1-\lambda)}{1-\sigma}$ such that the optimal decision of the representative firm implies a sequential organization of the production process. The equilibrium relation of intermediate inputs is, as a consequence, required to be $x_{c,a,S}(1-\lambda) = x_{c,b,S}$. Since the only factor of production is labor the latter relation involves the following equation of labor demands

$$\frac{(1-\lambda)L_{c,a,S}}{a} = \frac{L_{c,b,S}}{b}. \tag{3.7}$$

where $L_{c,a,S}$ ($L_{c,b,S}$) denotes labor demand for the production of intermediate $x_{c,a,S}$ ($x_{c,b,S}$). Similar to the case of a parallel process, the sequential structure implies a Leontief production function since the relation of factor inputs is a fixed ratio. However, as both intermediates are produced with a unique type of labor this does not constitute a drawback at this stage of the analysis. The respective labor demands of the production of intermediate

[15] See e.g. Costinot et al. (2011).

inputs are aggregated and imply that the labor market is cleared: $L = L_{c,a,S} + L_{c,b,S}$. In combination with the factor input relation of intermediate steps from (3.7) this results into $L_{c,b,S} = \frac{b(1-\lambda)L}{a+b(1-\lambda)}$. However, for the completion of the second intermediate stage $\frac{1-\lambda}{b}$ units of labor are required, implying that

$$Y_{c,S} = \frac{(1-\lambda)^2 L}{a + b(1-\lambda)} \tag{3.8}$$

units of the final good are produced. Similar to the parallel case, minimum unit cost equal marginal cost, $p = k_{c,S} = w_{c,S}\frac{a/(1-\lambda)+b}{1-\lambda}$, and the final good's price p is normalized to one. Consequently, the wage reads as:

$$w_{c,S} = \frac{(1-\lambda)^2}{a + b(1-\lambda)}. \tag{3.9}$$

Note that the marginal productivity of labor equals the wage rate. The former relates directly to intermediate input-specific factor requirements a and b and the country-level probability of making mistakes, λ. In contrast to the parallel production structure an assembly of intermediate inputs is not required and, accordingly, $\sigma\lambda$ does not determine $Y_{c,S}$ and $w_{c,S}$. However, the failure rate λ exhibits a multiplicative impact on the wage rate and output since the value added of the first intermediate input is exposed to destruction within the first *and* second intermediate production stage.

Proposition 3.3 *When sequential production is optimal, the wage rate and aggregate output decrease in the probability of making mistakes as well as in the required labor inputs for the production of each intermediate good. However, factor requirements of the first intermediate stage have a stronger negative impact, both in relation to the second step in sequential and to the first stage in parallel production.*

The wage rate as well as final good production is higher in sequential than in parallel production if and only if sequential production constitutes a firm's optimal choice.

The proof is given in Appendix 3.6.1. A higher probability of making mistakes implies a lower country-level productivity similar to the parallel production structure. This leads to a decrease in the aggregated output and the marginal productivity of labor which equals wages. Analogously, higher factor input requirements at either stage of the production process involve a lower productivity of labor and, consequently, lower wages and less output on the country-level. However, the impact of increased factor input requirements of the first intermediate stage (a) differs not only with respect to the second step (b) but also in comparison to its role in parallel production. First, since first step's value added is at risk both in the first and second intermediate stage, an increase in a involves a stronger negative impact on productivity than a rise in the labor requirement b that is only at risk in the second step. Second, the above disparity of the impact of first step's labor requirements applies also when comparing the sequential process to the parallel structure. Within the latter production process, the labor input a is exposed to the same probability of making mistakes than the value added implied by b, namely λ during the intermediate stage and $\sigma\lambda$ during assembly.

A natural outcome of perfectly competitive factor and output markets is that firm-level decisions coincide with efficient aggregated output and wage levels. As a consequence, the wage rate as well as aggregated final good quantities are higher in a sequential (parallel) production structure if and only if the firm chooses optimally a sequential (parallel) production process.

3.3.3 Endogenous Production Processes in Different Closed Economies

Our focus in the previous sections was to analyze under which conditions parallel and sequential production structures emerge on the country-level. For the following study of how globalization shapes and changes production processes we need to embed this country-level analysis within a world populated by several economies. Since intermediate production stages of the final good can be carried out within at most two different countries the assumption of two countries is sufficient for the analysis of endogenous production structures on a global scale. Therefore, we assume two countries that exhibit different probabilities of making failures in intermediate production stages (λ, λ^*) and different labor endowments (L, L^*), but are symmetric with respect to labor input requirements (a, b) as well as to the assembly-specific parameter of failure (σ). * denotes foreign variables and parameters. Without loss of generalization, we assume $\lambda^* > \lambda$. However, we will allow for $L^* \gtrless L$. An immediate result of disparities in failure rates is that firms' optimal choices on the production structure differ across countries since the threshold in (3.3) implies $\frac{\sigma(1-\lambda)}{1-\sigma} > \frac{\sigma(1-\lambda^*)}{1-\sigma}$.

Lemma 3.1 *Given that the domestic and foreign economy are closed,*

- *domestic and foreign firms choose* ***parallel*** *production if and only if* $\frac{a}{b} > \frac{\sigma(1-\lambda)}{1-\sigma}$.
- *domestic and foreign firms choose* ***sequential*** *production if and only if* $\frac{a}{b} < \frac{\sigma(1-\lambda^*)}{1-\sigma}$.
- *domestic firms choose* ***sequential*** *and foreign firms* ***parallel*** *production if and only if* $\frac{\sigma(1-\lambda^*)}{1-\sigma} < \frac{a}{b} < \frac{\sigma(1-\lambda)}{1-\sigma}$.

For relative value added within the range of $\frac{a}{b} \in (0,\infty)\setminus\left(\frac{\sigma(1-\lambda^*)}{1-\sigma}, \frac{\sigma(1-\lambda)}{1-\sigma}\right)$, there exist no disparities in the organization of production processes between countries in closed economy. In contrast, for $\frac{a}{b} \in \left(\frac{\sigma(1-\lambda^*)}{1-\sigma}, \frac{\sigma(1-\lambda)}{1-\sigma}\right)$, firms in the foreign country produce in optimum parallelly while sequential production is most efficient in the domestic country. Since the probability of making mistakes constitutes a measure of country-specific productivity we consider the domestic country as a more productive country while the foreign country represents a less productive country.

Lemma 3.2 *Wages and aggregated output are always higher in the domestic than in the foreign country.*

The proof is given in Appendix 3.6.1. A higher marginal productivity of labor implies higher wages and a greater aggregated output in the more productive country. Intuitively, more final goods are accomplished at home than abroad as the probability of failure, i.e. the risk of destroying the good at any intermediate production stage, is lower.

3.4 Production Structures in Open Economy

In open economy analysis, we assume that labor is immobile across countries while final goods can be freely traded without any costs. Moreover, intermediate inputs can be freely traded and production plants of intermediates can be located within any country without costs[16].

3.4.1 Global Production Processes

The global production structure depends on factor endowments (L, L^*), factor input requirements (a, b), the failure parameter of assembly (σ)[17], and country specific probabilities of making mistakes (λ, λ^*). Their relations determine the structure of production on a global scale as well as whether a country completely specializes in the production of a single intermediate stage. We define global sequential production as a process where at least one country completely specializes in one intermediate production stage. In contrast, parallel production processes do not necessarily imply that countries specialize.

Our analysis of how country-level disparities in failure rates shape the global organization of production implies that the representative firm of each country chooses endogenously its optimal production process. On the other hand, perfect competition on product and labor markets involves efficiency of market outcomes (i.e. firm-level decisions result in the highest attainable output). As a consequence, firms' optimal production structure and corresponding localization decisions are congruent with the production process that generates the efficient output level. In this vein, firms optimal decisions are revealed by a comparison of aggregated output levels that are generated by every feasible production process given parameters and endowments.

In closed economy, domestic firms choose a parallel production structure if and only if $\frac{a}{b} > \frac{\sigma(1-\lambda)}{1-\sigma}$ and foreign firms decide on parallel processes if and only if $\frac{a}{b} > \frac{\sigma(1-\lambda^*)}{1-\sigma}$. While $\lambda^* > \lambda$ implies that $\frac{\sigma(1-\lambda)}{1-\sigma} > \frac{\sigma(1-\lambda^*)}{1-\sigma}$ it also involves that the probability of making mistakes during assembly is higher abroad than at home: $\sigma\lambda^* > \sigma\lambda$. Since trade in intermediate inputs and final goods is costless and assembling does not incur labor costs, assembly is always carried out in the domestic country. This pattern however changes the threshold of a sequential versus a parallel production process abroad while it has no

[16] See e.g. Grossman and Rossi-Hansberg (2011) for an analysis of the impact of offshoring costs that differ across tasks.

[17] Note that although σ is equal across countries, the probabilities of making mistakes in assembly differ since $\sigma\lambda^* > \sigma\lambda$.

impact on the domestic country's trade-off. Similar to the analysis that leads to the closed economy threshold (3.3) firms in the foreign country will choose a parallel production structure in open economy if and only if

$$\begin{aligned} k_S^* &> k_{o,P}^* \\ \Longleftrightarrow \frac{\frac{aw^*}{1-\lambda^*} + bw^*}{1-\lambda^*} &> \frac{\frac{aw^*}{1-\lambda^*} + \frac{bw^*}{1-\lambda^*}}{1-\sigma\lambda} \\ \Longleftrightarrow \frac{a}{b} &> \frac{\sigma(1-\lambda^*)}{\frac{\lambda^*}{\lambda} - \sigma}. \end{aligned}$$

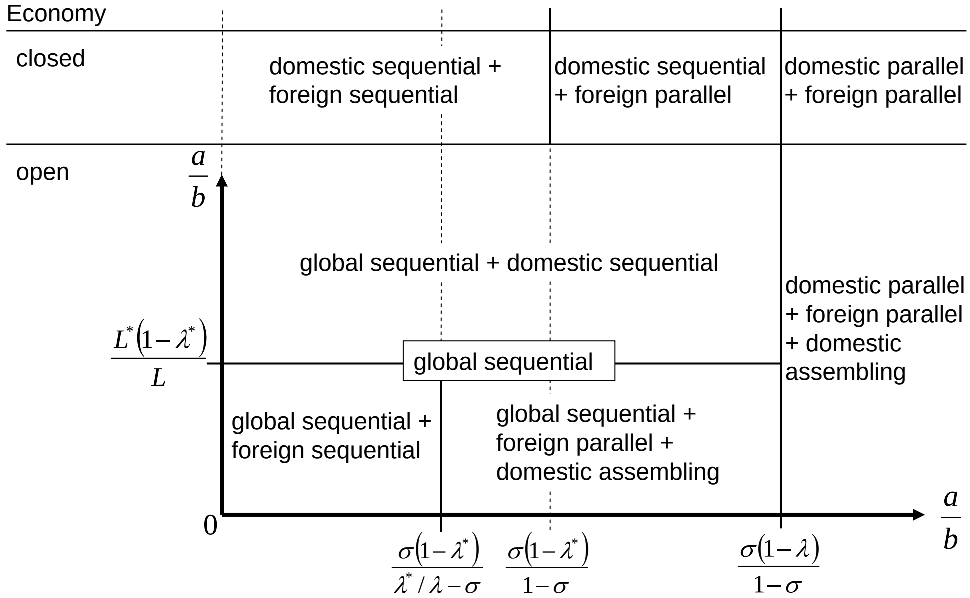
Note that since $\frac{\sigma(1-\lambda^*)}{\lambda^*/\lambda-\sigma} < \frac{\sigma(1-\lambda^*)}{1-\sigma}$ the threshold of parallel versus sequential production (abstracting from localization and specialization decisions) shifts to the left on the axis of relative value added, $\frac{a}{b}$ (see *Figure 3.4*).

Proposition 3.4 *Optimal firm decisions imply that the structure of the production process is*

- ***sequential*** *global and* **sequential** *domestic* $\Longleftrightarrow \frac{a}{b} > \frac{L^*(1-\lambda^*)}{L} \wedge \frac{a}{b} < \frac{\sigma(1-\lambda)}{1-\sigma}$.
- ***sequential*** *global* $\Longleftrightarrow \frac{a}{b} = \frac{L^*(1-\lambda^*)}{L} \wedge \frac{a}{b} < \frac{\sigma(1-\lambda)}{1-\sigma}$.
- ***sequential*** *global and* **sequential** *foreign* $\Longleftrightarrow \frac{a}{b} < \frac{L^*(1-\lambda^*)}{L} \wedge \frac{a}{b} < \frac{\sigma(1-\lambda^*)}{\lambda^*/\lambda-\sigma}$.
- ***sequential*** *global and* **parallel** *foreign* $\Longleftrightarrow \frac{a}{b} < \frac{L^*(1-\lambda^*)}{L} \wedge \frac{\sigma(1-\lambda^*)}{\lambda^*/\lambda-\sigma} < \frac{a}{b} < \frac{\sigma(1-\lambda)}{1-\sigma}$.
- ***parallel*** *in both countries* $\Longleftrightarrow \frac{a}{b} > \frac{\sigma(1-\lambda)}{1-\sigma}$.

The proof is given in Appendix 3.6.2. The proposition implies a two-dimensional matrix of relative value added's thresholds of failure rates and relative endowments that determine five distinct cases of the organization of global production processes. *Figure 3.4* illustrates these cases and opposes them to the situation of closed economies. Assume that relative value added of intermediate inputs equals relative factor endowments, $\frac{a}{b} = \frac{L^*(1-\lambda^*)}{L}$, while the ratio of $\frac{a}{b}$ implies a sequential production structure, $\frac{a}{b} < \frac{\sigma(1-\lambda)}{1-\sigma}$. Then, the foreign country completely specializes in the first intermediate stage while the domestic country completely specializes in the second step. Since the domestic country exposes the almost accomplished product in the second stage to a smaller risk of total loss it has therein a

Figure 3.4: Overview of (Global) Production Processes



Ricardian comparative advantage. Nevertheless, productivity in both production stages is higher at home than abroad as $(1-\lambda) > (1-\lambda^*)$.

Within the upper left corner of the open economy matrix, a global sequential production process emerges since $\frac{a}{b} < \frac{\sigma(1-\lambda)}{1-\sigma}$. Moreover, $\frac{a}{b} > \frac{L^*(1-\lambda^*)}{L}$ involves that along with a complete specialization on the first step abroad some domestic resources are employed in an additional sequential production process at home. For $\frac{a}{b} < \frac{L^*(1-\lambda^*)}{L}$, a global sequential structure emerges with a complete domestic specialization on the second intermediate step. Supplementary, foreign firms engage in sequential production within their country if $\frac{a}{b} < \frac{\sigma(1-\lambda^*)}{\lambda^*/\lambda-\sigma}$ and decide on a parallel process if $\frac{a}{b} > \frac{\sigma(1-\lambda^*)}{\lambda^*/\lambda-\sigma}$. Note that the respective threshold decreases compared to closed economy since assembly may be carried out in the domestic country at a lower probability of making mistakes. Since markets are perfectly competitive, intermediate inputs are shipped towards the domestic country without any costs and selling the final good at the world market price implies some subsequent re-exporting.

In the case of $\frac{a}{b} > \frac{\sigma(1-\lambda)}{1-\sigma}$, the choice of parallel production processes is optimal for domestic and foreign firms. Moreover, both types of intermediate inputs are produced in each country. As long as $\frac{a}{b} \neq \frac{L^*(1-\lambda^*)}{L(1-\lambda)}$, there exists no globalization with respect to the production of intermediate stages since disparities in labor productivities would prevent market clearing of inputs. Or, in contrast to a sequential production structure, high relative value added implies that cross-country differences in labor productivities do not any more determine the production structure and, consequently, location decisions. Nevertheless, as assembling requires no labor inputs and $1 - \sigma\lambda > 1 - \sigma\lambda^*$, it will be carried out in the domestic country. In the special case of $\frac{a}{b} = \frac{L^*(1-\lambda^*)}{L(1-\lambda)}$, the location of intermediate inputs production is undetermined while assembly is still concentrated in the domestic country. However, an analysis of domestic and foreign wage levels and the corresponding marginal productivities is required to get a more detailed understanding of how global production processes are shaped.

3.4.2 Wage Levels and Efficient Wages

Firms consider disparities in wages across countries in their decision on global production structures and the corresponding localization of plants. Moreover, the shape of global production processes determines the efficiency of domestic and foreign labor. A sequential global specialization in intermediate production stages e.g. implies a comparative advantage of domestic over foreign labor with respect to the second step. Since domestic labor is endowed with a higher productivity in every intermediate stage it also exhibits an absolute productivity advantage. However, relative scarcity of labor across countries resulting from specialization patterns may well counteract the effects of comparative and absolute advantages in production technologies. In general, free movement of production plants implies equal efficient wages across countries, involving that wages equalize after correcting for production structure-specific differences in technologies. Since the latter depend largely on global production processes we will analyze separately (efficient) wages for each case of *Proposition 3.4*. Note that we abstract in this section from indexing wages above the notion of being open economy foreign or domestic wages to save on notation. This implies that computed wages hold only within each of the following subsections.

Wage levels resulting from a global and domestic sequential production process

A relative value added greater than relative weighted factor endowments, $\frac{a}{b} > \frac{L^*(1-\lambda^*)}{L}$, and smaller than the domestic threshold of sequential versus parallel production, $\frac{a}{b} < \frac{\sigma(1-\lambda)}{1-\sigma}$, implies a sequential global production structure. Supplementary to the global specialization in intermediate stages, resources in the domestic country are used for sequential production. Perfect competition on the world market of the final good implies that $k^G_{o,S} = k_{o,S} = p$ where o denotes open economy variables and G specifies the globalization of intermediate production stages. p is the world market price which is equal across countries and normalized to one. As a consequence, $k_{o,S} = k_S = 1$ determines the wage level in the domestic country

$$w_o = \frac{(1-\lambda)^2}{a + b(1-\lambda)} \tag{3.10}$$

which equals the domestic wage in closed economy (3.9). Plugging the domestic wage rate into $k^G_{o,S} = \frac{aw^*_o/(1-\lambda^*)+bw_o}{1-\lambda} = 1$ results in the following foreign wage rate

$$w^*_o = \frac{(1-\lambda)(1-\lambda^*)}{a + b(1-\lambda)}. \tag{3.11}$$

$\frac{a}{b} > \frac{L^*(1-\lambda^*)}{L}$ implies that the foreign country completely specializes in the first intermediate production stage while the domestic country produces both types of inputs. Hence, domestic country-specific productivity amounts to $\frac{1}{1-\lambda}$ and foreign country-specific productivity to $\frac{1}{1-\lambda^*}$. Efficient wages thus equalize if $\frac{w_o}{1-\lambda} = \frac{w^*_o}{1-\lambda^*}$ which holds given (3.10) and (3.11).

Wage levels given complete specialization within a sequential global production process

While $\frac{a}{b} < \frac{\sigma(1-\lambda)}{1-\sigma}$ implies a global sequential production process $\frac{a}{b} = \frac{L^*(1-\lambda^*)}{L}$ involves complete specialization of intermediate production stages across countries. Since $\lambda^* > \lambda$, the domestic country specializes in the second intermediate stage to minimize the global risk of destroying the almost accomplished product. Complementary, the foreign country specializes in the first step. The world market price p equals marginal costs ($k^G_{o,S} = p = 1$) where $k^G_{o,S} = \frac{aw^*_o/(1-\lambda^*)+bw_o}{1-\lambda}$ and, consequently,

$$w_o = \frac{1-\lambda}{b} - \frac{a}{b}\frac{w^*_o}{1-\lambda^*}. \tag{3.12}$$

However, the above equation determines factor prices only up to a negative relationship between domestic and foreign wages while country-specific levels are undetermined since there exists no 'second' labor market (see e.g. the determination of the wages given in (3.10) and (3.11)). Moreover, Ricardian specialization in intermediate stages implies a Leontief-style production function. Calculating the impact of marginal deviations from $\frac{a}{b} = \frac{L^*(1-\lambda^*)}{L}$ given $\frac{a}{b} < \frac{\sigma(1-\lambda)}{1-\sigma}$ does not provide a remedy to undetermined wage levels since a slightly higher domestic labor supply or a marginally greater foreign endowment involves a different global production process.

Wage levels resulting from a sequential global and sequential foreign production process

Here, $\frac{a}{b} < \frac{\sigma(1-\lambda^*)}{\lambda^*/\lambda-\sigma}$ determines that any production structure that emerges will be sequential. Since $\frac{a}{b} < \frac{L^*(1-\lambda^*)}{L}$, the domestic country completely specializes while the foreign country additionally produces with a sequential structure. Perfect competition on the world market of the final good implies that $k^G_{o,S} = k^*_S = p = 1$ where $k^*_S = 1$ determines the wage level in the foreign country

$$w^*_o = \frac{(1-\lambda^*)^2}{a + b(1-\lambda^*)} \tag{3.13}$$

which equals the foreign country's closed economy wage ((3.9) for the foreign country). Subsequently, using (3.13) in $k^G_{o,S} = \frac{aw^*_o/(1-\lambda^*)+bw_o}{1-\lambda} = 1$, the domestic wage is computed as

$$w_o = \frac{a(\lambda^* - \lambda) + b(1-\lambda)(1-\lambda^*)}{b(a + b(1-\lambda^*))}.$$

Since the domestic country completely specializes in the second intermediate step, the calculation of its headstart in productivity has to take into account its comparative advantage in the second stage. The foreign country produces $\frac{1-\lambda^*}{a}$ units of x_a with one unit of labor and the domestic country has an advantage in producing one unit of x_b out of one unit of labor of $\frac{1-\lambda}{b} - \frac{1-\lambda^*}{b}$. As a consequence, the domestic comparative advantage amounts to $\left(\frac{a}{1-\lambda^*}\right) / \left(\frac{b}{1-\lambda-(1-\lambda^*)}\right) = \frac{a}{b}\frac{\lambda^*-\lambda}{1-\lambda^*}$. Since foreign labor is employed in the first and second intermediate stages of sequential production foreign country-specific productivity is $\frac{1}{1-\lambda^*}$ and efficient wages equalize:

$$\frac{w_o}{1-\lambda+\frac{a}{b}\frac{\lambda^*-\lambda}{1-\lambda^*}} = \frac{w_o^*}{1-\lambda^*}.$$

Note that the domestic wage is hence augmented by its comparative advantage given the specific (global) production structure where the final good has a higher completion probability of $1-\lambda-(1-\lambda^*)$ if the second intermediate stage is done in the domestic country.

Wage levels resulting from a sequential global and a parallel foreign production structure

Since relative value added is smaller than weighted foreign endowments, $\frac{a}{b} < \frac{L^*(1-\lambda^*)}{L}$, the domestic country completely specializes in the second step of a global sequential production process. The foreign country produces the complementary first step but employs also resources in a parallel production structure with domestic assembly as $\frac{\sigma(1-\lambda^*)}{\lambda^*/\lambda-\sigma} < \frac{a}{b} < \frac{\sigma(1-\lambda)}{1-\sigma}$. Perfect competition on output markets implies $k_{o,S}^G = k_P^* = p = 1$ and, hence, $k_P^* = 1$ determines the foreign wage level

$$w_o^* = \frac{(1-\lambda^*)(1-\sigma\lambda)}{a+b}. \tag{3.14}$$

Using the foreign wage (3.14) in $k_{o,S}^G = \frac{aw_o^*/(1-\lambda^*)+bw_o}{1-\lambda} = 1$ results in the domestic wage rate

$$w_o = \frac{b(1-\lambda)-a\lambda(1-\sigma)}{b(a+b)}. \tag{3.15}$$

Trading the final good without any costs implies that efficient wages across countries equalize:

$$\frac{w_o}{1-\lambda+\frac{\sigma\lambda(1-\lambda)-\frac{a}{b}\lambda(1-\sigma)}{1-\sigma\lambda}} = \frac{w_o^*}{1-\lambda^*}.$$

The foreign country-specific productivity is $\frac{1}{1-\lambda^*}$ since foreign labor produces both types of intermediate inputs. Domestic labor, however, has a comparative advantage in producing the second intermediate stage in the present global sequential production process. As a consequence, the domestic wage level (3.15) is adjusted upwards by more than its country-specific productivity, $\frac{1}{1-\lambda}$. Note that the adjustment factor $\frac{\sigma\lambda(1-\lambda)-\frac{a}{b}\lambda(1-\sigma)}{1-\sigma\lambda}$ is strictly positive as $\frac{a}{b} < \frac{\sigma(1-\lambda)}{1-\sigma}$. Moreover, it is the higher the smaller relative value added of intermediate steps is, i.e. the 'farther' a domestic country is from switching from sequential to parallel production structures. Since the latter would require a final assembly of intermediates, the term $\frac{1}{1-\sigma\lambda}$ enlarges the adjustment factor the more the higher the probability of making assembly mistakes ($\sigma\lambda$) is.

Wages resulting from parallel production processes

Relative value added that is greater than the threshold of sequential versus parallel production structures in the domestic country, $\frac{a}{b} > \frac{\sigma(1-\lambda)}{1-\sigma}$, implies that production processes within the domestic and the foreign country are of a parallel nature. Moreover, apart from the special case $\frac{a}{b} = \frac{L^*(1-\lambda^*)}{L(1-\lambda)}$, intermediate inputs are produced within each country to coincide exactly while assembly is carried out exclusively in the domestic country. No costs of trade in intermediate inputs involve $k_P^* = w_o^* \frac{a+b}{(1-\lambda^*)(1-\sigma\lambda)}$, while $k_P = w_o \frac{a+b}{(1-\lambda)(1-\sigma\lambda)}$ is similar to the closed economy case. Perfect competition on the final good market involves $k_P^* = k_P = p = 1$, implying that

$$w_o = \frac{(1-\lambda)(1-\sigma\lambda)}{a+b} \qquad \text{and} \qquad w_o^* = \frac{(1-\lambda^*)(1-\sigma\lambda)}{a+b}.$$

Since both countries do both intermediate production stages, the domestic country does not have any comparative advantage in a particular intermediate step. As a consequence, the domestic country-specific productivity is $\frac{1}{1-\lambda}$ and the foreign country's amounts to $\frac{1}{1-\lambda^*}$. Adjusting wages by country-specific productivities hence implies equalization of efficient wages: $\frac{w_o^*}{1-\lambda^*} = \frac{w_o}{1-\lambda}$.

3.4.3 Global Production Structures and Welfare

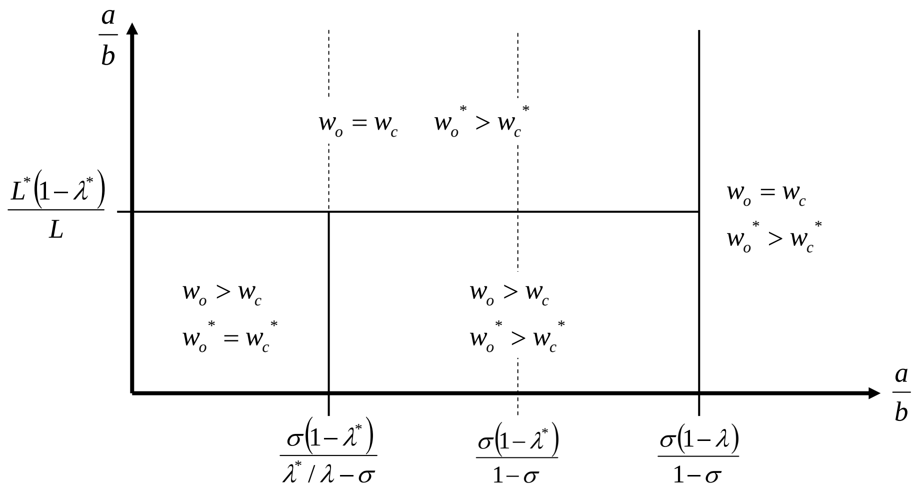
Globalization leads to the emergence of production structures that are optimal on a global scale and, accordingly, to the equalization of efficient wages across countries. Since there exist neither frictions on global goods and input markets nor on countries' labor markets, the efficiency gains from globalization directly translate into wage increases and, hence, welfare gains. However, whether wages increase throughout countries or welfare gains are concentrated within a single country is determined by the structure of global production.

Proposition 3.5 *Globalization of production processes implies that*

- *if* $\frac{a}{b} > \frac{L^*(1-\lambda^*)}{L} \wedge \frac{a}{b} < \frac{\sigma(1-\lambda)}{1-\sigma}$*, domestic wages are constant and foreign wages increase.*
- *if* $\frac{a}{b} < \frac{L^*(1-\lambda^*)}{L} \wedge \frac{a}{b} < \frac{\sigma(1-\lambda^*)}{\lambda^*/\lambda-\sigma}$*, domestic wages increase and foreign wages are constant.*
- *if* $\frac{a}{b} < \frac{L^*(1-\lambda^*)}{L} \wedge \frac{\sigma(1-\lambda^*)}{\lambda^*/\lambda-\sigma} < \frac{a}{b} < \frac{\sigma(1-\lambda)}{1-\sigma}$*, domestic and foreign wages increase.*
- *if* $\frac{a}{b} > \frac{\sigma(1-\lambda)}{1-\sigma}$*, domestic wages are constant and foreign wages increase.*

The proof is given in Appendix 3.6.2. An illustration of how the impact of globalization is determined by factor endowments, thresholds, and relative value added is provided in *Figure 3.5.* In general, globalization of production processes results in well-known

Figure 3.5: Welfare Effects of Globalization



Ricardian effects, i.e. that wage and welfare of a country that specializes completely in the production of a good increase. Within our analysis, this implies that a country focuses completely on carrying out a single intermediate production stage. Given a global sequential production structure where there is supplementary a domestic sequential $\left(\frac{a}{b} > \frac{L^*(1-\lambda^*)}{L} \wedge \frac{a}{b} < \frac{\sigma(1-\lambda)}{1-\sigma}\right)$ or foreign sequential process $\left(\frac{a}{b} < \frac{L^*(1-\lambda^*)}{L} \wedge \frac{a}{b} < \frac{\sigma(1-\lambda^*)}{\lambda^*/\lambda-\sigma}\right)$, we observe exactly this pattern. In the former case, the foreign country completely specializes in the first intermediate production step and, thus, foreign wages are higher in open than in closed economy. In contrast, domestic labor produces both types of intermediates and its wage level is not affected by opening the economy. Similarly, in the latter case, the domestic country completely specializes in the second intermediate stage and the domestic wage rate increases through globalization. Inversely, foreign labor is employed in both intermediate production steps and, as a consequence, its wage level is not altered.

However, the results of our model differ from Ricardo (1817)'s if the production process throughout countries is not of a pure sequential structure. First, if $\left(\frac{a}{b} < \frac{L^*(1-\lambda^*)}{L} \wedge \frac{\sigma(1-\lambda^*)}{\lambda^*/\lambda-\sigma} < \frac{a}{b} < \frac{\sigma(1-\lambda)}{1-\sigma}\right)$ the foreign country produces parallel the final good, whereas the global production structure is sequential. Although not being completely specialized on the production of a single intermediate step, the foreign workers gain in terms of wages. They benefit from the fact that the assembly of intermediate inputs is carried out in the domestic country with a lower risk of destroying the almost accomplished product. Nevertheless, in line with the idea of Ricardian comparative advantage, the domestic wage level increases since the domestic country completely focuses on the production of the second intermediate stage.

Second, if $\frac{a}{b} > \frac{\sigma(1-\lambda)}{1-\sigma}$, neither country specializes in a particular production stage[18]. In this case, domestic production does not gain in efficiency from globalization and, thus, domestic wage levels do not increase. Nevertheless, foreign production benefits from the less failure-prone assembly of intermediate inputs in the domestic country and, as a consequence, the foreign wage level rises. Apart from gains of shifting assembly to the domestic country, there are no benefits from opening the economy if parallel production structures prevail. Nevertheless, since globalization increases the foreign threshold of sequential versus parallel production there exists a substantial range of relative value added where foreign workers gain in terms of wages. Summing up, globalization is most beneficial for sequential production structures as e.g. in the case of Costinot et al. (2011)'s analysis, whereas the positive impact given parallel processes is less clear cut.

[18]Note that countries could specialize if $\frac{a}{b} = \frac{L^*(1-\lambda^*)}{L(1-\lambda)}$. In this case, they would be indifferent with respect to specialization.

3.5 Conclusion

We introduce a new model of endogenous firm-level decisions on the optimal structure of production processes. Production of the final good requires two intermediate stages that are either carried out parallel or sequentially. Within each intermediate production step, there exists a probability of making mistakes that would destroy the product. A sequential structure implies that a specific intermediate step is done first and the resulting product is processed in a second step to the final good. The parallel process implies simultaneous production of inputs that are subsequently assembled to the final good. Whether firms choose the former or the latter process depends on the trade-off between relative valued added of intermediate inputs and the probability of making mistakes in intermediate steps and assembly. A sequential production process is chosen if the relative valued added of the first step is rather small, or, if the probability of making mistakes within intermediate stages is relatively petite. In contrast, a rather high relative valued added of the first step, a high failure rate within intermediate steps, or a low probability of loosing the intermediates during assembly involves the choice of a parallel production structure.

In open economy, a variety of different production patterns emerge that depend on relative factor endowments, relative value added, and country specific probabilities of making mistakes. In this study, we show that the case of complete specialization across intermediate production steps as in Costinot et al. (2011) constitutes a special case that is characterized by a low relative value added of the first intermediate production steps. For higher relative value added, a global parallel production structure emerges where country-specific probabilities of making mistakes lose their impact on endogenous localization decisions. As a consequence, welfare effects of the globalization of production processes depend on the specific value added of intermediates and on the probability of making mistakes within countries. In particular, high relative value added of the first production step precludes the emergence of sequential production processes on a global scope, excluding Ricardian welfare gains from specialization across countries.

3.6 Appendix A3

3.6.1 Closed Economy Proofs

Proof of Lemma 3.2

For relative value added within the range of $\frac{a}{b} \in (0,\infty)\backslash\left(\frac{\sigma(1-\lambda^*)}{1-\sigma},\frac{\sigma(1-\lambda)}{1-\sigma}\right)$ the result follows immediately from our comparative statics results in *Proposition 3.2* and *Proposition 3.3*. For $\frac{a}{b} \in \left(\frac{\sigma(1-\lambda^*)}{1-\sigma},\frac{\sigma(1-\lambda)}{1-\sigma}\right)$, the foreign country produces parallelly while the domestic country chooses sequential production. From (3.9) and (3.6) for the domestic and foreign country, respectively, we show that

$$\begin{aligned} w_{c,S} &> w^*_{c,P} \\ \iff \frac{(1-\lambda)^2}{a+b(1-\lambda)} &> \frac{(1-\lambda^*)(1-\sigma\lambda^*)}{a+b} \\ \iff \frac{a}{b}\left((1-\lambda)^2-(1-\lambda^*)(1-\sigma\lambda^*)\right) &> (1-\lambda)\left((1-\lambda^*)(1-\sigma\lambda^*)-(1-\lambda)\right) \end{aligned}$$

where $(1-\lambda)^2-(1-\lambda^*)(1-\sigma\lambda^*) \gtreqless 0$. If $(1-\lambda)^2 > (1-\lambda^*)(1-\sigma\lambda^*)$, it immediately follows that $w_{c,S} > w^*_{c,P}$ since $(1-\lambda^*)(1-\sigma\lambda^*)-(1-\lambda) < 0$ due to the fact that $\lambda^* > \lambda$ and $\frac{a}{b} > 0$. If $(1-\lambda)^2 < (1-\lambda^*)(1-\sigma\lambda^*)$, the above inequality becomes

$$\frac{a}{b} < (1-\lambda)\underbrace{\frac{(1-\lambda^*)(1-\sigma\lambda^*)-(1-\lambda)}{(1-\lambda)^2-(1-\lambda^*)(1-\sigma\lambda^*)}}_{>\frac{\sigma}{1-\sigma}}$$

which holds since

$$\begin{aligned} \frac{(1-\lambda^*)(1-\sigma\lambda^*)-(1-\lambda)}{(1-\lambda)^2-(1-\lambda^*)(1-\sigma\lambda^*)} &> \frac{\sigma}{1-\sigma} \\ \iff (1-\lambda^*)(1-\sigma\lambda^*)-(1-\lambda)+\sigma(1-\lambda) &< \sigma(1-\lambda)^2 \\ \iff (1-\lambda^*)(1-\sigma\lambda^*) &< (1-\lambda)(1-\sigma\lambda). \end{aligned}$$

and $\lambda^* > \lambda$. As $\frac{a}{b} < \frac{\sigma(1-\lambda)}{1-\sigma}$, it holds that $w_{c,S} > w^*_{c,P}$. As a result, $w_{c,S} > w^*_{c,P}$ for $\frac{a}{b} \in \left(\frac{\sigma(1-\lambda^*)}{1-\sigma},\frac{\sigma(1-\lambda)}{1-\sigma}\right)$ and, consequently, $w_{c,S} > w^*_{c,P}$ holds $\forall\frac{a}{b}$.

Proof of Proposition 3.3

Proof of a first stage's stronger impact in case of a sequential structure:

From (3.9) and (3.6),

$$\frac{\frac{\partial w_{c,S}}{\partial a}}{\frac{\partial w_{c,S}}{\partial b}} > \frac{\frac{\partial w_{c,P}}{\partial a}}{\frac{\partial w_{c,P}}{\partial b}} \iff \frac{1}{1-\lambda} > 1.$$

The same reasoning applies to $Y_{c,S} > Y_{c,P}$ as $Y_c = w_c L$.

Proof of higher wages and output levels given optimal firm decisions:

From (3.8) and (3.5),

$$\begin{aligned} Y_{c,S} &> Y_{c,P} \\ \iff \frac{(1-\lambda)}{a+b(1-\lambda)} &> \frac{1-\sigma\lambda}{a+b} \\ \iff 0 &> a(\lambda-\sigma\lambda) - b\sigma\lambda(1-\lambda) \\ \iff \frac{\sigma\lambda(1-\lambda)}{\lambda-\sigma\lambda} &> \frac{a}{b} \end{aligned}$$

which is the condition that a firm chooses optimally sequential production. The same reasoning applies to $w_{c,S} > w_{c,P}$ as $Y_c = w_c L$.

3.6.2 Open Economy Proofs

Proof of Proposition 3.4

Within this proposition we will compare different production structures given specific relations of endowments and parameters. In particular, the world production structure will be revealed in each case by extracting the most efficient, i.e. the highest, output level. Recurring production structures are the following:

Computation of $Y^G_{o,S}$:

A global sequential production process implies that output is given by $Y^G_{o,S} = \frac{(1-\lambda)(1-\lambda^*)}{a} L^*$ or, alternatively, by $Y^G_{o,S} = \frac{1-\lambda}{b} L$.

Computation of $Y^*_{o,P}$:

In a globalized world, the foreign country is able to increase its output given parallel production by doing the assembly in the domestic country: $Y^*_{o,P} = \frac{(1-\lambda^*)(1-\sigma\lambda)}{a+b} L^*$.

Greater weighted domestic endowments, $\frac{L^*(1-\lambda^*)}{a} < \frac{L}{b}$, given that $\frac{a}{b} < \frac{\sigma(1-\lambda)}{1-\sigma}$

Computation of $Y^d_{o,S}$:

Complete specialization of the foreign country in the production of x_a implies in this case that also some output of intermediate product x_a is produced at home. As $\frac{a}{b} < \frac{\sigma(1-\lambda)}{1-\sigma}$ production at home is necessarily sequential. A global sequential production process implies $\frac{L^*(1-\lambda^*)}{a} = \frac{L^f_{o,b,S}}{b}$ and sequential production at home involves $\frac{L^d_{o,a,S}(1-\lambda)}{a} = \frac{L^d_{o,b,S}}{b}$. Plugging both into domestic labor market clearing, $L = L^d_{o,a,S} + L^f_{o,b,S} + L^d_{o,b,S}$, results in

$$\begin{aligned} L &= \frac{aL^d_{o,b,S}}{b(1-\lambda)} + \frac{bL^*(1-\lambda^*)}{a} + L^d_{o,b,S} \iff L^d_{o,b,S} = \frac{L - \frac{b}{a}L^*(1-\lambda^*)}{1+\frac{a}{b(1-\lambda)}} \\ \text{and} \quad Y^d_{o,S} &= (1-\lambda)\frac{L - \frac{b}{a}L^*(1-\lambda^*)}{b+\frac{a}{1-\lambda}}. \end{aligned}$$

Proof that $Y^G_{o,S} + Y^d_{o,S} > Y^G_{o,P}$ holds:

A comparison of aggregated results reads as

$$\begin{aligned} Y^G_{o,S} + Y^d_{o,S} &> Y^G_{o,P} \\ \iff \frac{(1-\lambda^*)(1-\lambda)}{a}L^* + (1-\lambda)\frac{L - \frac{b}{a}L^*(1-\lambda^*)}{b+\frac{a}{1-\lambda}} &> \\ \frac{1-\sigma\lambda}{a+b}\left[(1-\lambda)L + (1-\lambda^*)L^*\right] & \\ \iff (1-\lambda^*)(1-\lambda)L^* + (1-\lambda)\frac{aL - bL^*(1-\lambda^*)}{b+\frac{a}{1-\lambda}} &> \\ \frac{a(1-\sigma\lambda)}{a+b}\left[(1-\lambda)L + (1-\lambda^*)L^*\right] & \end{aligned}$$

$$
\begin{aligned}
\iff ((1-\lambda)b+a)(a+b)(1-\lambda^*)(1-\lambda)L^* + (1-\lambda)^2(a+b)(aL - bL^*(1-\lambda^*)) &> \\
((1-\lambda)b+a)a(1-\sigma\lambda)\left[(1-\lambda)L + (1-\lambda^*)L^*\right] & \\
\iff (1-\lambda^*)L^*\Big[(1-\lambda)((1-\lambda)b+a)(a+b) - (1-\lambda)^2(a+b)b - ((1-\lambda)b+a)a(1-\sigma\lambda)\Big] &> \\
(1-\lambda)aL\left[((1-\lambda)b+a)(1-\sigma\lambda) - (1-\lambda)(a+b)\right] & \\
\iff (1-\lambda^*)L^*\underbrace{\left[(1-\lambda)(a+b) - ((1-\lambda)b+a)(1-\sigma\lambda)\right]}_{>0} &> \\
(1-\lambda)L\underbrace{\left[((1-\lambda)b+a)(1-\sigma\lambda) - (1-\lambda)(a+b)\right]}_{<0} &
\end{aligned}
$$

since

$$
\begin{aligned}
(1-\lambda)(a+b) - ((1-\lambda)b+a)(1-\sigma\lambda) &> 0 \\
\iff -\lambda a + \sigma\lambda((1-\lambda)b+a) &> 0 \\
\iff (1-\lambda) + \frac{a}{b} &> \frac{a}{b}\frac{1}{\sigma} \\
\iff \frac{\sigma(1-\lambda)}{1-\sigma} &> \frac{a}{b}.
\end{aligned}
$$

Consequently, $Y^G_{o,S} + Y^d_{o,S} > Y^G_{o,P}$ holds.

Proof that $Y^G_{o,S} + Y^d_{o,S} > Y_S + Y^*_{o,P}$ holds:

A comparison of aggregated results reads as

$$
\begin{aligned}
Y^G_{o,S} + Y^d_{o,S} &> Y_S + Y^*_{o,P} \\
\iff \frac{(1-\lambda^*)(1-\lambda)}{a}L^* + \frac{(1-\lambda)^2}{a+b(1-\lambda)}\left(L - \frac{b}{a}L^*(1-\lambda^*)\right) &> \frac{(1-\lambda)^2 L}{a+b(1-\lambda)} + \frac{(1-\lambda^*)(1-\sigma\lambda)L^*}{a+b} \\
\iff \frac{1-\lambda}{a} - \frac{1-\sigma\lambda}{a+b} &> \frac{(1-\lambda)^2}{a+b(1-\lambda)}\frac{b}{a} \\
\iff (1-\lambda)(a+b(1-\lambda)) - b(1-\lambda)^2 &> \frac{a(a+b(1-\lambda))(1-\sigma\lambda)}{a+b} \\
\iff \frac{\sigma(1-\lambda)}{1-\sigma} &> \frac{a}{b}
\end{aligned}
$$

and, since $\frac{\sigma(1-\lambda)}{1-\sigma} > \frac{a}{b}$ holds in this case, $Y^G_{o,S} + Y^d_{o,S} > Y_S + Y^*_{o,P}$. As a consequence, given the endowments and parameters, a global sequential production structure with an additional domestic sequential production emerges.

Equal weighted factor endowments, $\frac{L^*(1-\lambda^*)}{a} = \frac{L}{b}$*, given that* $\frac{a}{b} < \frac{\sigma(1-\lambda)}{1-\sigma}$

Proof that $Y^G_{o,S} > Y^G_{o,P}$ holds:

A comparison of sequentially and parallel produced aggregated output implies

$$Y^G_{o,S} > Y^G_{o,P} \iff \frac{(1-\lambda)(1-\lambda^*)}{a}L^* > \frac{1-\sigma\lambda}{a+b}\left[(1-\lambda)L + (1-\lambda^*)L^*\right],$$

where plugging in $\frac{L^*(1-\lambda^*)}{a} = \frac{L}{b}$ leads to

$$\begin{aligned} \frac{1-\lambda}{a} &> \frac{1-\sigma\lambda}{a+b}\left[(1-\lambda)\frac{b}{a}+1\right] \\ \iff (1-\lambda)(a+b) &> (1-\sigma\lambda)\left[(1-\lambda)b+a\right] \\ \iff \frac{a}{b}(1-\lambda-(1-\sigma\lambda)) &> (1-\sigma\lambda)(1-\lambda)-(1-\lambda) \\ \iff \frac{a}{b} &< \frac{\sigma(1-\lambda)}{1-\sigma}. \end{aligned}$$

As $\frac{a}{b} < \frac{\sigma(1-\lambda)}{1-\sigma}$, it holds that $Y^G_{o,S} > Y^G_{o,P}$.

Proof that $Y^G_{o,S} > Y_S + Y^*_{o,P}$ holds:

A comparison of global sequentially versus domestic sequentially and foreign parallel produced aggregated output implies

$$Y^G_{o,S} > Y_S + Y^*_{o,P} \iff \frac{(1-\lambda)(1-\lambda^*)}{a}L^* > \frac{(1-\lambda)^2 L}{a+b(1-\lambda)} + \frac{(1-\lambda^*)(1-\sigma\lambda)L^*}{a+b},$$

where plugging in $\frac{L^*(1-\lambda^*)}{a} = \frac{L}{b}$ leads to

$$\begin{aligned} \frac{(1-\lambda)(a+b)-a(1-\sigma\lambda)}{b(a+b)} &> \frac{(1-\lambda)^2}{a+b(1-\lambda)} \\ \iff \sigma(a+b-\lambda b) &> a \\ \iff \frac{\sigma(1-\lambda)}{1-\sigma} &> \frac{a}{b}. \end{aligned}$$

As $\frac{\sigma(1-\lambda)}{1-\sigma} > \frac{a}{b}$, it holds that $Y^G_{o,S} > Y_S + Y^*_{o,P}$.

Proof that $Y^G_{o,S} > Y_S + Y^*_S$ holds:

A comparison of global sequentially versus domestic foreign sequentially produced aggregated output implies

$$Y_{o,S}^{G} > Y_S + Y_{S}* \iff \frac{(1-\lambda)(1-\lambda^*)}{a}L^* > \frac{(1-\lambda)^2 L}{a+b(1-\lambda)} + \frac{(1-\lambda^*)^2 L^*}{a+b(1-\lambda^*)},$$

where plugging in $\frac{L^*(1-\lambda^*)}{a} = \frac{L}{b}$ leads to

$$1-\lambda > \frac{(1-\lambda)^2 b}{a+b(1-\lambda)} + \frac{a(1-\lambda^*)}{a+b(1-\lambda^*)} \iff \lambda^* > \lambda.$$

Since we assume $\lambda^* > \lambda$, it holds that $Y_{o,S}^{G} > Y_S + Y_S^*$.

Greater weighted foreign endowments, $\frac{L^*(1-\lambda^*)}{a} > \frac{L}{b}$, given that $\frac{a}{b} < \frac{\sigma(1-\lambda)}{\lambda^*/\lambda-\sigma}$

Since in autarky sequential production is optimal abroad and at home, two production structures could emerge in the world, given endowments and parameters. First, the domestic country could specialize in the production of x_b while in the foreign some additional production is done sequentially ($Y_{o,S}^{G} + Y_{o,S}^{*d}$). Second, production could be sequentially but separately done within each country ($Y_S + Y_S^*$).

Computation of $Y_{o,S}^{*d}$:

Complete specialization of the domestic country in the production of x_b implies that also some output of intermediate product x_b is produced in the foreign country. A global sequential production process implies $\frac{L_{o,a,S}^{*f}(1-\lambda^*)}{a} = \frac{L}{b}$ and sequential production abroad involves $\frac{L_{o,a,S}^{*d}(1-\lambda^*)}{a} = \frac{L_{o,b,S}^{*d}}{b}$. Plugging both into foreign labor market clearing, $L^* = L_{o,a,S}^{*d} + L_{o,b,S}^{*f} + L_{o,b,S}^{*d}$, results in

$$\begin{aligned} L^* &= \frac{aL_{o,b,S}^{*d}}{b(1-\lambda^*)} + \frac{aL}{b(1-\lambda^*)} + L_{o,b,S}^{*d} \iff L_{o,b,S}^{*d} = \frac{L^* - \frac{a}{b}\frac{L}{1-\lambda^*}}{1+\frac{a}{b(1-\lambda^*)}} \\ \text{and} \quad Y_{o,S}^{*d} &= \frac{(1-\lambda^*)L^* - \frac{a}{b}L}{b+\frac{a}{1-\lambda^*}}. \end{aligned}$$

Proof that $Y^G_{o,S} + Y^{*d}_{o,S} > Y_S + Y^*_S$ holds:

$$\begin{aligned}
Y^G_{o,S} + Y^{*d}_{o,S} &> Y_S + Y^*_S \\
\iff \frac{(1-\lambda)L}{b} + \frac{(1-\lambda^*)L^* - \frac{a}{b}L}{b + \frac{a}{1-\lambda^*}} &> \frac{(1-\lambda)^2 L}{a+b(1-\lambda)} + \frac{(1-\lambda^*)^2 L^*}{a+b(1-\lambda^*)} \\
\iff (1-\lambda)\left(\frac{1}{b} - \frac{1-\lambda}{a+b(1-\lambda)}\right) &> (1-\lambda^*)\frac{\frac{a}{b}}{a+b(1-\lambda^*)} \\
\iff 1-\lambda &> (1-\lambda^*)\frac{a+b(1-\lambda)}{a+b(1-\lambda^*)} \\
\iff \lambda^* &> \lambda
\end{aligned}$$

where $\lambda^* > \lambda$ and, thus, $Y^G_{o,S} + Y^{*d}_{o,S}$ emerges.

Greater weighted foreign endowments, $\frac{L^*(1-\lambda^*)}{a} > \frac{L}{b}$, given that $\frac{\sigma(1-\lambda^*)}{\lambda^*/\lambda-\sigma} < \frac{a}{b} < \frac{\sigma(1-\lambda)}{1-\sigma}$

Since in autarky parallel production is optimal abroad and sequential production is chosen at home, three production structures could emerge in the world, given endowments and parameters. First, there could emerge a parallel process on the global scope ($Y^G_{o,P}$). Second, the domestic country could produces sequentially and the foreign parallel while assembling at home ($Y_S + Y^*_{o,P}$). Third, a complete specialization at home emerges with some parallel production abroad ($Y^G_{o,S} + Y^{*d}_{o,P}$).

Computation of $Y^{*d}_{o,P}$:

A global sequential production process implies

$$\frac{L^{*f}_{o,a,S}(1-\lambda^*)}{a} = \frac{L}{b} \tag{A3.1}$$

and parallel production within the foreign country requires

$$\frac{L^{*d}_{o,a,P}}{a} = \frac{L^{*d}_{o,b,P}}{b} \tag{A3.2}$$

where $L^{*f}_{o,a,S}$ is foreign labor demand for sequential gloabal production and $L^{*d}_{o,a,P}$, $L^{*d}_{o,b,P}$ represent foreign labor demands in the case of foreign parallel production for intermediate goods x_a and x_b, respectively. Plugging (A3.1) and (A3.2) into foreign labor market clearing, $L^* = L^{*f}_{o,a,S} + L^{*d}_{o,a,P} + L^{*d}_{o,b,P}$, results in $L^{*d}_{o,a,P} = \frac{a}{a+b}(L^* - L^{*f}_{o,a,S})$ and with (A3.1) in

$$
\begin{aligned}
L^{*d}_{o,a,P} &= \frac{a}{a+b}\left(L^* - \frac{a}{b}\frac{L}{1-\lambda^*}\right) \\
\text{and, thus,} \quad Y^{*d}_{o,P} &= \frac{(1-\sigma\lambda)(1-\lambda^*)}{a}\frac{a}{a+b}\left(L^* - \frac{a}{b}\frac{L}{1-\lambda^*}\right).
\end{aligned}
$$

<u>Proof that $Y^G_{o,S} + Y^{*d}_{o,P} > Y^G_{o,P}$ holds:</u>

Comparing aggregated production levels implies

$$
\begin{aligned}
Y^G_{o,S} + Y^{*d}_{o,P} &> Y^G_{o,P} \\
\Longleftrightarrow \frac{1-\lambda}{b}L + \frac{(1-\sigma\lambda)(1-\lambda^*)}{a+b}\left(L^* - \frac{a}{b}\frac{L}{1-\lambda^*}\right) &> \frac{1-\sigma\lambda}{a+b}\left[(1-\lambda)L + (1-\lambda^*)L^*\right] \\
\Longleftrightarrow \left(\frac{a}{b}+1\right)(1-\lambda)L + (1-\sigma\lambda)(1-\lambda^*)L^* - \frac{a}{b}(1-\sigma\lambda)L &> (1-\sigma\lambda)(1-\lambda)L + (1-\sigma\lambda)(1-\lambda^*) \\
\Longleftrightarrow \frac{a}{b}(1-\lambda)L - \frac{a}{b}(1-\sigma\lambda)L &> -\sigma\lambda(1-\lambda)L \\
\Longleftrightarrow \frac{a}{b} &< \frac{\sigma(1-\lambda)}{1-\sigma}.
\end{aligned}
$$

As $\frac{a}{b} < \frac{\sigma(1-\lambda)}{1-\sigma}$, it holds that $Y^G_{o,S} + Y^{*d}_{o,P} > Y^G_{o,P}$.

<u>Proof that $Y^G_{o,S} + Y^{*d}_{o,P} > Y_S + Y^*_{o,P}$ holds:</u>

Comparing aggregated production levels reveals

$$
\begin{aligned}
Y^G_{o,S} + Y^{*d}_{o,P} &> Y_S + Y^*_{o,P} \\
\Longleftrightarrow \frac{1-\lambda}{b}L + \frac{(1-\sigma\lambda)(1-\lambda^*)}{a+b}\left(L^* - \frac{a}{b}\frac{L}{1-\lambda^*}\right) &> \frac{(1-\lambda)^2 L}{a+b(1-\lambda)} + \frac{(1-\sigma\lambda)(1-\lambda^*)L^*}{a+b} \\
\Longleftrightarrow (1-\lambda)\left(\frac{1}{b} - \frac{1-\lambda}{a+b(1-\lambda)}\right) &> \frac{1-\sigma\lambda}{a+b}\frac{a}{b} \\
\frac{\sigma(1-\lambda)}{1-\sigma} &> \frac{a}{b}.
\end{aligned}
$$

Since $\frac{\sigma(1-\lambda)}{1-\sigma} > \frac{a}{b}$, it holds that $Y^G_{o,S} + Y^{*d}_{o,P} > Y_S + Y^*_{o,P}$.

Proof of Proposition 3.5

Within this proof, we abstract from wage indexes others than those that denote domestic, foreign, open, and closed economy variables implying that the specific wage levels hold only for the explicit factor endowments and parameters.

Proof in the case of $\frac{L^*(1-\lambda^*)}{a} > \frac{L}{b}$ and $\frac{a}{b} < \frac{\sigma(1-\lambda^*)}{\lambda^*/\lambda-\sigma}$:

As the foreign wage is constant only domestic wages has to be compared, where $w_o > w_c$ holds if and only if

$$\begin{aligned} \frac{a(\lambda^*-\lambda)+b(1-\lambda)(1-\lambda^*)}{b(a+b(1-\lambda^*))} &> \frac{(1-\lambda)^2}{a+b(1-\lambda)} \\ \Longleftrightarrow a^2(\lambda^*-\lambda) &> 0. \end{aligned}$$

Proof in the case of $\frac{L^*(1-\lambda^*)}{a} > \frac{L}{b}$ and $\frac{\sigma(1-\lambda^*)}{\lambda^*/\lambda-\sigma} < \frac{a}{b} < \frac{\sigma(1-\lambda)}{1-\sigma}$:

As the foreign wage is constant only domestic wages has to be compared, where $w_o > w_c$ holds if and only if

$$\begin{aligned} \frac{b(1-\lambda)-a\lambda(1-\sigma)}{b(a+b)} &> \frac{(1-\lambda)^2}{a+b(1-\lambda)} \\ \Longleftrightarrow \frac{\sigma(1-\lambda)}{1-\sigma} &> \frac{a}{b}. \end{aligned}$$

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