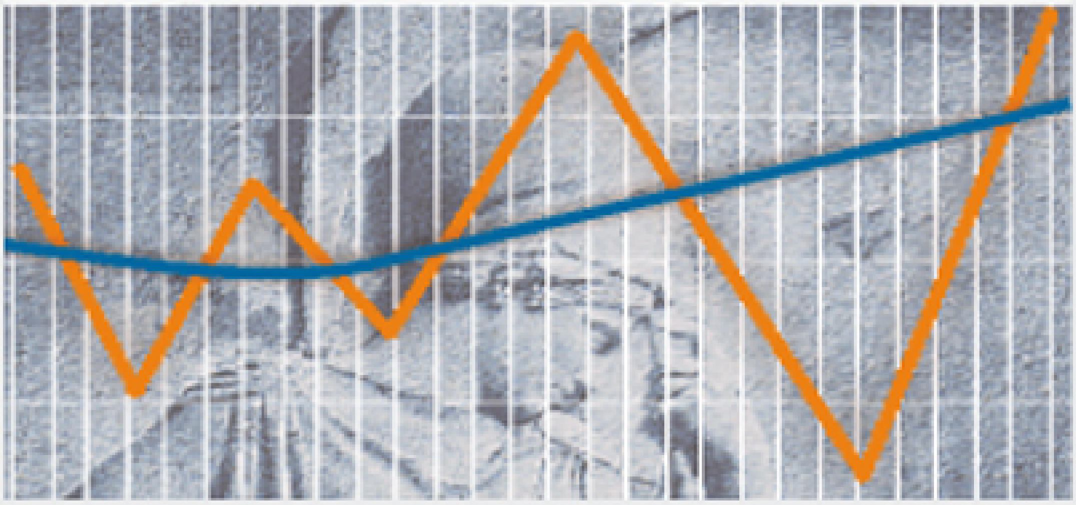

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Essays on Offshoring, Wage Inequality and Innovation

Sebastian Benz

ifo Institut

Leibniz-Institut für Wirtschaftsforschung an der Universität München e.V.

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Preface

This volume was prepared by Sebastian Benz while he was working at the Ifo Institute. It was completed in December 2013 and accepted as a doctoral thesis by the Department of Economics at the University of Munich. It includes five self-contained chapters. All chapters discuss different implications of the growing importance of trade in intermediate inputs. The first chapter compares the impact of international trade in intermediate inputs (offshoring) on wage inequality in two distinct but similar framework. In the first framework the profitability of offshoring is based on increasing returns to scale on the task-level, whereas the second framework relies on differences in relative factor endowments of the two countries involved in offshoring. The second chapter provides a theory of offshoring under imitation risk that explains optimal dynamic adjustments of firms' offshoring decisions and yields two new channels by which offshoring affects wage inequality. Chapter 3 studies the impact of intellectual property rights and of offshoring costs on the rate of innovation and on the offshoring intensity. In chapter 4 I estimate knowledge spillovers through outsourcing relationships between German firms, measured by the number of those firms' successful patent applications. The last chapter describes sector-level input-output relationships in eleven European economies and estimates the importance of international trade in intermediate inputs and internationally mobile capital for the interdependence of output shocks in those countries.

Keywords: Imitation, innovation, input-output analysis, intellectual property rights, intermediate inputs, international capital mobility, international income inequality, knowledge spillovers, offshoring, outsourcing, patents, Rybczynski effects, skill premium, trade in tasks

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Finally, I would not have come this far without the constant love and support from my parents. Thank you for always being there for me. Last but not least, during the last three years I was accompanied by Agnes. Your continuous encouragement, your patience, and your loving support means everything to me.

Essays on Offshoring, Wage Inequality, and Innovation

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Introduction

What is now commonly referred to as offshoring was first pointed out in the modern literature by Jones and Kierzkowski (1990). They noted that advances in the technology of transport and communication facilitate an increasing fragmentation of value chains. In open economies, production processes would thus no longer need to take place within certain countries, but would instead be spread out across the world. About 10 years later, Hummels et al. (2001), Yeats (2001), and Yi (2003) have shown that Jones and Kierzkowski (1990) had a point: International division of labor had become significantly more vertical in nature. Almost 20 years later, Grossman and Rossi-Hansberg (2008) have sharpened our view by a new theoretical paradigm which they call task trade, as opposed to trade in goods. Their model emphasizes that offshoring is a new form of globalization that is different from (although related to) both trade in goods and international migration with new implications on wage inequality.

Notwithstanding the fast progress of knowledge during those years there are still many open questions. One of these open issues is the differential impact of different motives for offshoring on key variables of interest, such as income inequality. Traditionally, offshoring was motivated by lower wages for production workers in a developing country, either by ad-hoc assumption or due to asymmetric factor endowments. Another motive for offshoring, especially between developed economies, are external economies of scale. This type of offshoring was only explored recently by Grossman and Rossi-Hansberg (2012) in a model with increasing returns on the country-level. They handle the obvious problem of multiple equilibria by assuming that individual firms can internalize the external scale economies by specializing in single tasks and supplying these tasks to the entire world. This is in line with the assumption of small firms because the share of each task in aggregate output has a measure zero.

In Chapter 1 of my dissertation, joint work with Wilhelm Kohler, we compare the implications of offshoring due to increasing returns (North-North offshoring) and offshoring due to differences in relative endowments (North-South offshoring). The first type of offshoring is modelled in the tradition of Grossman and Rossi-Hansberg (2012), where high-skilled managers constitute a fixed input into production while low-skilled production workers constitute a variable input. Production tasks can potentially be taken over by low-skilled production workers in a foreign country. Production is subject to increasing returns to scale on the country-level. These increasing returns come from specialization on the level of production tasks, so that the equilibrium offshoring pattern is determined by a trade-off between wages of production workers and the task-specific productivity in production. We stick to the assumption of a non-homothetic production technology with managers as fixed input and production workers as variable input when analyzing offshoring due to differences in relative endowments. However, the effect of increasing returns to scale is neutralized by focusing on relative endowment changes that do not affect total output of the two countries differentially.

In this environment, two questions are of specific relevance. First, what happens when two countries intensify their offshoring relationship? And second, what is the effect of symmetric or asymmetric changes in endowments with high-skilled and low-skilled workers? The first question requires a careful understanding of the quantitative importance of exogenous variation. Specifically, we argue that the only meaningful comparison of the two models should be based on quantitatively identical changes in the intensity of offshoring, even though the underlying changes in the cost of offshoring may differ.

The second question can only be answered within the setup of each model. On the one hand, since offshoring due to increasing returns to scale requires identical relative endowments of the two countries, we can only analyze the effect of endowment changes that leave relative endowments unchanged, but change the relative size of the two countries involved in offshoring. On the other hand, since offshoring due to relative factor endowments requires the two countries to be identical in terms of output, we can only analyze the effect of changes in relative endowments that leave aggregate output levels equal.

We demonstrate that offshoring due to relative factor endowments has a dramatically larger effect on wage inequality within the Northern economy than offshoring due to external economies of scale. Moreover, in the latter case, wage inequality may even decline when the offshoring intensity exceeds a certain threshold. The effect of offshoring on inequality across the two countries exhibits a non-monotonic pattern in both cases, however in opposite directions. Inequality between two countries with symmetric endowments where offshoring is driven by increasing returns is concave and has a maximum at intermediate levels of offshoring. This means that the larger country benefits more from initial offshoring while the smaller country benefits more from later stages. In contrast, inequality between two countries with differences in relative is convex. This implies that the manager-abundant country benefits less from initial offshoring and gains more from later stages of offshoring.

Even though offshoring is driven by two different mechanism in chapter 1 of my dissertation, both work through the channel of production cost differences between two countries. However, recent research by Branstetter et al. (2011) shows that a further crucial determinant of the offshoring intensity is the protection of intellectual property rights. Thus, chapter 2 of my dissertation extends a standard offshoring model, where production tasks are performed by low-skilled workers, with information leakage, so that cost savings from offshore production must be traded off with the implied increase in the imitation risk. The model is developed in two steps. In a first step I analyze the implications of imitation risk on firms' offshoring decisions in a static model. In a second step I introduce a dynamic adjustment mechanism, in which the relative number of northern to southern varieties is determined by changes in the imitation rate.

I perform a structural estimation of the model to quantify the perceived imitation risk when firms from developed countries use intermediate inputs from China. The estimated baseline imitation risk is between 6 per cent and 12 per cent and indicates the perceived probability that a product is imitated if just a marginal share of its intermediate inputs come from China. When imports of intermediate inputs from China account for 20 per cent of local manufacturing value added, as observed for Korea in 2008, the implied perceived imitation probability rises to levels between 15 per cent and 30 per cent.

Explicitly modelling research&development (R&D) allows me to analyze the transition path of the offshoring volume from one steady-state to another, as a reaction to exogenous shocks. It is characterized by initial overshooting when technological offshoring costs are reduced. Subsequently, the offshoring level converges downwards to the new steady-state. Decomposing wage effects from offshoring I can identify an intertemporal profit effect and a composition effect, which complement the well-known productivity effect and labor supply effect from Grossman and Rossi-Hansberg (2008). Whereas the intertemporal profit effect reduces wage inequality, because it reduces the value of every new variety and reduces the salary of high-skilled researchers, the composition effect increases wage inequality, because the reduction in the share of northern varieties implies less demand for northern production workers.

Moreover, I can show that wage inequality reacts non-monotonically to changes of the offshoring volume. Whereas Grossman and Rossi-Hansberg (2008) argue that the correlation of changes in offshoring and changes in wage inequality depends on the initial offshoring intensity, in this dynamic model it is the pattern of technology shocks over time that plays a crucial role. Specifically, a strong one-time reduction of offshoring costs may induce a different correlation of changes in offshoring and changes in wage inequality, than an identical reduction of offshoring costs that is spread out over a longer time horizon.

The results in chapter 2 describe how firms optimally adjust their production structure when offshoring affects the rate of imitation. However, it is very likely that the risk of imitation also has an impact on incentives for research & development. This question is subject of Chapter 3 of my dissertation. It builds on models of the product cycle literature initiated by Grossman and Helpman (1991a) and extended by Helpman (1993), Lai (1998), Glass and Saggi (2002), and Branstetter and Saggi (2009), amongst others.

The model is similar to the one presented in the previous chapter. Production is sliced into tasks that can potentially be performed offshore at the cost of iceberg offshoring costs and increased imitation risk. The rate of innovation in the North is endogenously determined by the size of the Northern research sector. Since workers are free to move between research and production, both occupations must pay equal wages. Consequently, cost savings from offshoring that influence production workers' wages via several channels as described in the previous chapter, have important repercussions in the Northern research sector.

This setup allows me to analyze the effects of two policy measures. First, southern policy makers can improve the protection of intellectual property rights in their country. This implies that the expected number of successful imitations decreases for a given research effort in the South. In equilibrium, it leads to a reduction of the innovation rate in the North, accompanied by an ambiguous change in the offshoring volume. Moreover, I look at the effects of a reduction of iceberg offshoring costs between the two countries. This leads to higher offshoring intensity, while it has an ambiguous effect on the rate of innovation and the rate of imitation.

Not only *international* trade in intermediate inputs may lead to a flow of knowledge that fosters R&D, but also intermediate inputs trade within a country. In chapter 4 of my dissertation, joint work with Mario Larch and Markus Zimmer, we quantify such knowledge spillovers through intermediate inputs trade in Germany. The estimation is based on a match of firm-level patent data from *Patstat* with firm level information from the *Amadeus* database. From *Patstat* we extract information on annually patenting activity. This allows us to use a measure of new patents as left-hand side variable, while we approximate the knowledge stock of each firm by the accumulated sum of patents.

Since intermediate goods trade of these firms cannot be observed, we construct a measure of bilateral firm-level trade from sector-level input-output tables and firm-level information on aggregate purchases of intermediate inputs. This measure of trade intensity is used to construct different knowledge capital stocks as weighted averages of firm-level knowledge stocks. Specifically, we can compare the relative importance of forward and backward linkages and the relative importance of inter-industry to intra-industry flows.

We find that knowledge spillovers from trading intermediate inputs within a country are important predictors of innovative success as measured by patent output. Forward spillovers seem to be more important than backward spillovers. This means that using inputs from innovative firms is more important for successful R&D than delivering inputs to innovative firms. Moreover, we find that inter-industry spillovers seem to be more important than intra-industry spillovers. This can potentially be explained by the fact that firms in the same industry are not only trading partners but may also be competitors in a small consumer market. Having very innovative competitors may reduce a firm's profits and thus erode opportunities for investment in R&D.

Also chapter 5 of my dissertation is joint work with Mario Larch and Markus Zimmer. In this chapter we quantify the importance of trade in intermediate inputs and capital mobility in transmitting endowment shocks across the countries of the European Union. The chapter extends a recent paper by Fisher and Marshall (2011) who develop a technique to calculate Rybczynski effects, using only data on factor input requirements and input-output data. Their strategy is based on the assumption that small endowment changes leave factor prices unchanged so that the production technology is characterized by constant input coefficients.

The extension to a multi-country setup yields several advantages. In terms of result, it allows us to quantify the importance of different channels of international interaction.

Specifically, we can separately identify the contribution of internationally traded intermediate inputs and internationally mobile capital for the propagation of shocks through the European economy. In terms of methodology, it provides justification to the assumption that factor prices are unaffected by endowment changes. If all factors are employed in the initial equilibrium, factor prices should be equal in all countries. If additional factors can be absorbed in production, maintaining full employment, also the new equilibrium should be characterized by factor price equalization so that endowment shocks have no influence on factor prices.

We find that positive shocks to labor endowment in one country have negative effects on output in most other countries, when foreign intermediate inputs are required for production. With additional mobile capital, the negative effects on other countries are even bigger. However, the country that experience the positive endowment shock can substantially increase its output, indicating flows of capital from unaffected countries to the country affected by the endowment shock.

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

Chapter 1

Managerial Versus Production Wages: Offshoring, Country Size and Endowments*

1.1 Introduction

In this paper, we explain the pattern of international trade in narrowly defined production tasks through the interplay of three forces: (i) the cost of offshore performance of tasks, (ii) the advantage from local concentration of task performance by many firms, and (iii) the abundance in different countries of production labor, relative to managerial labor. Local concentration of tasks is advantageous because of external economies of scale. Thus, firms located in different countries may *jointly* gain if they *all* locate a certain task in a single country, provided that offshoring the task is not too costly. Intuitively, if countries are symmetric in their relative labor endowments this gain should be particularly large for firms located in a relatively small country. Country size thus becomes an important determinant of task trade. However, if countries differ in their relative endowments with production and managerial labor the local availability of production labor becomes a crucial constraint for the concentration of tasks, and *relative labor abundance*, in addition to *country size*, becomes an important determinant of trade in tasks.

*This chapter is based on joint work with Wilhelm Kohler, forthcoming in the Canadian Journal of Economics, Vol. 47(1), 2014. Earlier versions have been published as CESifo Working Paper No. 3292, 2010, and University of Tuebingen, Working Papers in Economics and Finance No. 13, 2011.

We build upon Grossman and Rossi-Hansberg (2012) who are the first to provide an analysis of relative country size as a determinant of task trade driven by external economies of scale. They identify possible equilibrium patterns of task trade between two countries that share the *same relative labor endowment*, but differ in size. They also show that such trade is a potential source of wage differences across countries that would otherwise have the same wage rates. The authors argue convincingly that scale economies are an important characteristic of modern industrial production that may explain two-way task trade between similar countries. Such "North-North" offshoring is empirically important, but it cannot be explained by models of offshoring that rely on comparative advantage, such as Grossman and Rossi-Hansberg (2008).

We depart from the analysis by Grossman and Rossi-Hansberg (2012) in two ways. First, we look at task trade between countries that *differ in relative endowment* with managerial and production labor. Secondly, we ask new questions inspired by policy concerns about inequality. Grossman and Rossi-Hansberg (2012) focus on inter-country comparisons of production wages. We look at within-country income distribution, i.e., managerial wage income relative to production wages, as well as cross-country inequality in terms of income per capita. We ask how these two types of income distribution are affected by varying country size and asymmetric endowment changes if trade is restricted to final goods. We then seek answers to these same questions for a world with trade in tasks. We identify possible equilibrium patterns of task trade between asymmetric countries and offer numerical simulations that highlight orders of magnitude in the relationship between offshoring and within-country as well as between-country inequality.

These extensions of Grossman and Rossi-Hansberg (2012) are motivated in part by an empirical observation which is summarized in table 1.1. As is well known, the premium of US non-production over US production wages has been on an upward trend over the two decades from 1984 to 2005. However, there were ups and downs. Looking at annual changes, for 16 years we observe increases, and for 6 years we observe reductions. Table 1.1 presents average annual increases and reductions of the managerial wage premium for these two types of years, alongside average annual changes in the volumes of offshoring to developing and developed countries, respectively.[1] Years with a rising wage inequality were characterized

[1]We define as developed economies the European countries, Canada, Japan, Australia, and New Zealand. Adding the Republic of Korea, Singapore, Taiwan, or South Africa does not change the picture significantly. Wage data are from the NBER productivity database, offshoring is measured by US manufacturing imports of goods from US majority-owned foreign affiliates from the Bureau of Economic Analysis. The managerial

Table 1.1: US managerial wage premium and levels of offshoring

Average annual changes (%) 1984-2005

	number of years	managerial wage (s) relative to production wage (w)	Offshoring to developing countries	Offshoring to developed countries
rising s/w	16	1.06	14.78	8.98
falling s/w	6	-1.79	1.93	5.76

Sources: Wage data from the NBER productivity data base, offshoring from Bureau of Economic Analysis.

by substantially higher growth rates of offshoring and this pattern is more pronounced for offshoring with developing countries. Of course, all of this does not establish any causality, but if there is a causal relationship between the managerial wage premium and offshoring, then these numbers suggest that offshoring to developing countries may be different from, and more important than offshoring to other industrial countries.

But what is the exact meaning of the distinction between production labor and non-production (or managerial) labor? We argue that identifying production workers with low-skilled and non-production (or managerial) workers with high-skilled labor, as often done in the literature, is highly questionable. Putting this question aside, Grossman and Rossi-Hansberg (2012) stress a different distinction. They assume that managers constitute the fixed input, while production labor is a variable input. This is in line with a strand of literature which explains income distributions through indivisibilities that are typically inherent in managerial activities.[2] To the extent that skill levels play a role for self-selection into activities, this literature is able to explain why the resulting managerial wage premia are sometimes far larger than the underlying educational premia.[3] Nonetheless, in focusing on

premium decreased in 1985, 1986, 1997, 2001, 2002, and 2004 and increased in all other years between 1984 and 2005.

[2]It is worth quoting from a classic paper: *"Management involves discrete and indivisible choices and commands, such as which goods to produce, in what varieties and volume, and how to produce them. Supervision insures that management directives are carried through at the production level. Indivisibilities inherent in management decisions are represented analytically as a form of total factor productivity improvement and, as such, imply a strong scale economy, not unlike a public good but limited to the confines of the firm. For example, the decision of which good to produce is largely independent of scale, applying equally well to a very large enterprise as to a very small one."* (Rosen, 1982, p. 312) .

[3]There are very few models of trade that incorporate similar distinctions between fixed and variable inputs. The only examples we are aware of are Manasse and Turrini (2001) and Egger and Kreickemeier (2012). The vast majority of the literature assumes homothetic technologies where all inputs are used in the same proportions for both fixed and variable costs; see Horn (1983). For an example that focuses on the traditional skill premium, see Epifani and Gancia (2008).

task trade driven by external scale economies for production labor, coupled with managerial labor as a fixed input, this model seems particularly well suited to address income distribution effects of globalization and endowment asymmetry.

In terms of methodology, Grossman and Rossi-Hansberg (2012) achieve a major breakthrough in identifying a trading equilibrium that is mostly unique. This is in sharp contrast to earlier literature on trade with external scale economies, which has emphasized the potential for multiple equilibria, driven by history as well as well as arbitrary, but self-fulfilling expectations.[4] The tendency to generate multiple equilibria has always been viewed as a liability, which perhaps explains why this literature has taken somewhat of a back seat in modern trade theory. However, Grossman and Rossi-Hansberg (2010) have shown that this tendency to a large extent disappears if one assumes, plausibly, that firms engage in Bertrand-type price competition aimed at capturing entire world markets.[5] This serves as a mechanism that effectively solves the coordination failure caused by scale economies being an externality. In Grossman and Rossi-Hansberg (2012), what delivers this mechanism is a firm's ability to perform a task not just for its own, but also fot others through an outsourcing relationship.

In terms of results, Grossman and Rossi-Hansberg (2012) establish that the equilibrium of task concentration is unique, provided that offshoring is sufficiently costly and countries are not too similar in size. Ranking tasks according to the costliness of offshore performance, a robust pattern of two-way task trade emerges. A range of tasks that are least costly to offshore is concentrated in the smaller country. A range of tasks that feature higher cost of offshoring is concentrated in the larger country. Potentially, the range of tasks where offshoring is particularly costly is not traded at all. This generates a characteristic pattern of production wages. The country that hosts concentrated performance of the intermediate range of tasks where offshoring is more costly enjoys the advantage of not having to bear this cost, importing task that are less costly to offshore. Accordingly, it can pay higher wages to its production workers.[6]

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[4]Important contributions to this literature are Markusen and Melvin (1981), Ethier (1982a), Matsuyama (1991), and Krugman (1991).

[5]With this change in firm behavior comparative advantage regains its force in determining trade patterns, provided that each industry is negligibly small, so that capturing the entire world market never overstretches a country's resource constraint. The analytical trick to achieve "smallness "is to assume a continuum of industries.

[6]This effect is very similar to the so-called home market effect, first noted by Krugman (1980). That literature, however, assumes *internal* economies of scale. In models that feature differentiated intermediate inputs, as pioneered by Ethier (1982b), internal economies in input production translates into *external*

Our paper adds a number of new and interesting results. First, we provide comparative static results on inequality and asymmetric endowment changes for a world of prohibitive costs of offshoring. The domestic inequality effects are straightforward, but the effects on *international inequality*, measured by the ratio of incomes per capita, are more involved. While becoming larger through equi-proportional endowment changes is always gainful, the same is not true if a country becomes larger with a changing composition of the labor force. We establish a condition under which a positive productivity effect from scale economies dominates a negative terms-of-trade effect. In a similar fashion, we investigate how a changing composition of the labor force affects *real wages* for production and managerial labor within a country. While cross effects are dominated by the usual complementarity, own effects are ambiguous. Again, we establish conditions under which scale effects are dominating. Introducing task trade, we show that hosting a substantial amount of concentrated task performance generally lowers a country's aggregate managerial wage income, relative to aggregate income of its production workers.

Our main analytical result relates to the *pattern of task trade* between countries that are equal in size, but *asymmetric in relative endowments*. There are two types of equilibria. On the one hand, if the cost of offshoring across all tasks surpasses a certain threshold value, the country with a higher ratio of production to managerial labor endowment has a lower production wage, and task trade will be one-way with this country exporting tasks against imports of final goods. On the other hand, for a sufficiently low cost of task trade three scenarios are possible. If endowment asymmetry is above a certain threshold, this same pattern of one-way task trade and wages arises. If relative endowments are exactly equal to the threshold value, one-way task trade still prevails but wages of production workers in the two countries are equal. For sufficiently similar endowments, there exists a unique equilibrium with equal production wages, but with two-way task trade and a pattern of task concentration that is indeterminate. The potential of two-way trade is thus reduced as soon as we depart from symmetry. This is due to the above mentioned disciplinary force of Bertrand-type pricing strategies aimed at capturing entire world markets.

Our numerical results highlight non-monotonicities in the relationship between the level of offshoring and income inequality. Comparing incomes per capita across countries, we find

economies of scale for final goods production. However, since these are *international* in scope country, size plays a much different role for trade compared to a case where economies of scale are *national* in scope, as assumed here; see Ethier (1979).

that a lower cost of offshoring works in favor of the larger country as well as in favor of the production labor abundant country, provided that the initial level of offshoring is zero or small, induced by the concentration of tasks in these countries. However, if the initial level of task trade is already large this effect is dominated by the (second-order) cost-savings effect on inframarginal tasks. This effect weighs more heavily for the smaller country as well as the country with a relatively low production labor endowment, both of which import a larger range of tasks. Comparing incomes of managers and production workers within symmetric countries, we find that a lower cost of offshoring initially works in favor of manager incomes. But once the level of offshoring rises beyond a certain threshold, such that the marginal task is governed by a global (instead of a local) deviation condition, a lower cost of offshoring works in favor of production wages.

The remainder of our paper is structured as follows. The next section looks at the case where trade is restricted to final goods alone, meaning prohibitive trade costs for individual tasks. It derives analytical results for the comparative statics of inequality with respect to symmetric and asymmetric endowment changes. Section 1.3 then introduces trade in tasks. We abstain from reiterating any of the results obtained in Grossman and Rossi-Hansberg (2012) and look at the asymmetric case, deriving propositions on aggregate within-country inequality as well as the possible task trade equilibria. Section 1.4 finally turns to numerical simulations, tracing out measures of internal and between-country inequality for alternative combinations of offshoring levels and measures of size and asymmetry in the two countries' endowment with managerial and production labor. Section 1.5 concludes with a brief summary.

1.2 Trade in final goods

In order to highlight the role of offshoring as explanatory factor for inequality, both within and across countries, we first explore a world with trade only in final goods where inequality is determined by country size and relative endowments. In this section, we present this baseline model as a reference point for a world with trade in tasks which is presented subsequently.

1.2.1 Model setup

Following Grossman and Rossi-Hansberg (2012), we assume two countries, home and foreign (denoted by *), sharing identical preferences and technology but differing in their exogenous endowments of managerial labor M (M^*) and production workers L (L^*). Both types of labor are immobile across countries. Preferences feature "love of variety", modeled through a Dixit-Stiglitz-type utility function for symmetric varieties of a single final good. Producing any variety requires hiring f *managers* as a *fixed input*. In addition, production requires a *continuum of different tasks*, indexed by $i \in [0, 1]$, to be performed by *production workers*. Firms are headquartered in the country where they hire their managers.[7]

Given Dixit-Stiglitz preferences, final goods producers have price-setting power and charge a markup over marginal cost equal to $\sigma/(\sigma - 1) > 1$, where $\sigma > 1$ is the elasticity of substitution between any two varieties.[8] Assuming free entry, the number of firms is given by

$$n = M/f \quad \text{and} \quad n^* = M^*/f, \tag{1.1}$$

and competitive managerial wages are determined from the condition that all profits end up in managerial income:

$$s = \frac{cx}{\sigma - 1}\Big/ f \quad \text{and} \quad s^* = \frac{c^* x^*}{\sigma - 1}\Big/ f, \tag{1.2}$$

where c and c^* are marginal cost from production workers employed by a firm headquartered in the home and the foreign economy, respectively, and with x and x^* denoting quantities produced and sold of final goods.[9] There are no trade costs for final goods; hence, goods market equilibrium requires

$$\frac{x^*}{x} = \left(\frac{c^*}{c}\right)^{-\sigma}. \tag{1.3}$$

We use $1/A(i)$ to denote the amount of labor needed per unit of task i, if performed in the home economy, and analogously for the foreign economy. Due to external economies

[7] We make no distinction between firms hiring managers and managers setting up their own firm. In equilibrium, a manager must earn the same income, whether in terms of entrepreneurial profit, if self-employed, or through a perfect contract with a firm.

[8] This assumes a negligible influence of a single firm's pricing policy on the overall price index of varieties, which implies a sufficiently large number of firms and thus sufficiently large endowments $M + M^*$.

[9] Equation (1.2) follows from setting $x(p-c) - sf = x[\sigma/(\sigma-1) - 1]c - sf = 0$. This replaces the zero-profit condition found in conventional models of monopolistic competition.

of scale that are *national* in scope, $A(i)$ depends on the entire amount of task i performed domestically.[10]

We now define $\tilde{c}(w)$ as the unit cost function for a final good that arises for a firm headquartered in the home country, if trade is possible only for *final goods*, and analogously for $\tilde{c}^*(w^*)$. All tasks are needed in equal amounts and the entire amount of all tasks required per unit of the final good is assumed to be of measure 1. Following Grossman and Rossi-Hansberg (2012), we model scale economies in constant elasticity form, such that $A(i) := (nx)^\theta$, with $0 < \theta < 1$. By analogy, $A^*(i) := (n^*x^*)^\theta$, and unit costs emerge as

$$\tilde{c}(w) = \frac{w}{(nx)^\theta} \quad \text{and} \quad \tilde{c}^*(w^*) = \frac{w^*}{(n^*x^*)^\theta}. \tag{1.4}$$

Given these assumptions, $w\big/(nx)^\theta$ and $w^*\big/(n^*x^*)^\theta$ may also be interpreted as the cost of performing a unit of any task, respectively, in the home and the foreign economy.[11] The labor market equilibrium for production workers requires

$$L = (nx)^{1-\theta} \quad \text{and} \quad L^* = (n^*x^*)^{1-\theta}. \tag{1.5}$$

1.2.2 Comparative statics of inequality

Substituting equation (1.4) into (1.2) and using equations (1.1) and (1.5) we obtain the managerial wage premium in the home and the foreign economy as

$$\frac{s}{w} = \frac{L}{M(\sigma-1)} \quad \text{and} \quad \frac{s^*}{w^*} = \frac{L^*}{M^*(\sigma-1)}. \tag{1.6}$$

The managerial premium is not affected by changes in country size that do not alter the relative endowment. However, changing the composition of the workforce affects the managerial premium with the expected sign.

In the next step, we look at cross-country inequality in terms of income per head in the home, relative to the foreign economy. We define:

$$R := \frac{w}{w^*} \frac{(\lambda_M s/w + \lambda_L)}{(\lambda_{M^*} s^*/w^* + \lambda_{L^*})}, \tag{1.7}$$

[10] The external nature of scale economies in tasks is consistent with the assumption of perfect competition.
[11] These scale economies do not translate into scale economies on the final goods level. Final goods producers take marginal costs c and c^* as given parametrically.

where $\lambda_M = M/(M+L)$ is the share of managers in the home economy, and equivalently for all other shares. The home wage is governed by commodity market clearing (1.3), which leads to $w/w^* = (x/x^*)^{-1/\sigma}(xn)^{\theta}(x^*n^*)^{-\theta} = (x/x^*)^{\theta-1/\sigma}(n/n^*)^{\theta}$. Taking into account full employment of production workers, $x/x^* = (L/L^*)^{1/(1-\theta)}(n^*/n)$, and using $n^*/n = M^*/M$, we arrive at

$$\frac{w}{w^*} = \left(\frac{M}{M^*}\right)^{1/\sigma} \left(\frac{L}{L^*}\right)^{\frac{(\theta\sigma-1)}{(1-\theta)\sigma}}. \tag{1.8}$$

This allows us to solve for our measure of cross-country inequality:

$$R = \frac{M^*+L^*}{M+L} \left(\frac{M}{M^*}\right)^{1/\sigma} \left(\frac{L}{L^*}\right)^{\frac{\sigma-1}{(1-\theta)\sigma}}. \tag{1.9}$$

Equation (1.9) tells us that a change in the composition of endowment has an asymmetric influence on international inequality. Holding L constant, we obtain

$$\frac{\hat{R}}{\hat{M}} = \frac{1}{\sigma} - \lambda_M, \tag{1.10}$$

which is positive if the degree of substitution σ is low or the share of managers in home endowment λ_M is small. Intuitively, a higher number of managers implies a lower output per firm which leads to a terms of trade improvement, which is larger, the smaller σ. However, each manager now employs less production workers. This reduces the volume of sales for residual profit claims. The lower the initial share of managers in the workforce, the smaller is the resulting negative effect on aggregate income.

Holding M constant we obtain

$$\frac{\hat{R}}{\hat{L}} = -\frac{1}{\sigma(1-\theta)} + \frac{\theta}{1-\theta} + \lambda_M. \tag{1.11}$$

For obvious reasons, the terms-of-trade effect and residual profit effect now run in the opposite direction, again determined by σ and λ_M. In addition, there is a positive productivity effect which increases with the magnitude of scale economies θ.

For equi-proportional changes of L and M we obtain

$$\frac{\hat{R}}{\hat{M}} = -\frac{\theta}{\sigma(1-\theta)} + \frac{\theta}{1-\theta} > 0 \quad \forall \quad \hat{M} = \hat{L} \tag{1.12}$$

which is simply the sum of equation (1.10) and equation (1.11) so that a positive productivity effect dominates a negative terms-of-trade effect. We summarize these results in the following proposition.

Proposition 1 (International inequality). A change in the composition of factor endowment in one country has an ambiguous effect on international inequality. In contrast, a country unambiguously gains from becoming larger with a constant composition of the labor force.

Proof. See the comparative statics in equations (1.10) to (1.12). □

All of these *relative wage* effects may be interpreted as *relative welfare* effects for the respective group of workers, provided that trade in final goods is free and costless, as assumed. Consumers in both countries then pay identical prices for final goods, and they also face the same degree of variety. However, one needs to be cautious when considering absolute levels of *real* wages. Two additional channels need to be taken into account for real wages. The first is a change in variety that follows from any change in a country's endowment of managers; see the managerial labor market equilibrium condition (1.1) above. With "love for variety", such changes are of direct relevance for real wages. The second channel runs through final goods prices, which are related to marginal cost by a constant markup. From (1.4) and (1.5), marginal costs in the home and the foreign economy are related to endowment changes according to

$$\widehat{c} = \hat{w} - \hat{L}/(1-\theta) \quad \text{and} \quad \widehat{c}^{*} = -\hat{L}^{*}/(1-\theta). \tag{1.13}$$

It is relatively straightforward to extend the above analysis to real wages. Denoting the exact price index dual to Dixit-Stiglitz preferences, $P := \left(Mp^{1-\sigma} + M^{*}p^{*1-\sigma}\right)^{1/(1-\sigma)}$, and using $w_r := w/P$ to define the real production wage, we obtain

$$\hat{w}_r = \frac{1}{\sigma}\left(1 + \frac{\sigma\gamma}{\sigma-1}\right)\hat{M} + \frac{1}{\sigma\,(1-\theta)}\left(\theta\sigma - 1 + \gamma\right)\hat{L}. \tag{1.14}$$

By complete analogy, endowment changes entail a change in real manager income according to

$$\hat{s}_r = \frac{1}{\sigma}\left(1 - \sigma + \frac{\sigma\gamma}{\sigma-1}\right)\hat{M} + \frac{1}{\sigma\,(1-\theta)}\left(\sigma - 1 + \gamma\right)\hat{L}. \tag{1.15}$$

In these equations, the term $\gamma := M\,(p/P)^{1-\sigma} > 0$ is equal to the income share that is spent on domestic varieties. We summarize the above equations in the following proposition

Proposition 2 (Real factor rewards). Real income of any factor unambiguously rises if the endowment of the other factor increases. In contrast, endowment changes generally have an ambiguous effect on own real income.

Proof. See the comparative statics in equations (1.14) and (1.15). □

1.3 Trade in production tasks

We now proceed to describe a world where trade is extended to production tasks. Grossman and Rossi-Hansberg (2012) focus on country size effects, assuming *symmetry* in *relative* endowments. An important purpose of this paper is to explore *asymmetry* in *relative* endowments with production and managerial labor.

1.3.1 Model setup

In line with the literature, we assume a continuum of tasks indexed by $i \in [0; 1]$ and that performing a certain task i outside the country of a firm's headquarter requires an additional amount of labor by a factor $\beta\tau(i) \geq 1$ from the country where the task is located. We order tasks according to the ease with which they can be dislocated, whence $\tau'(i) > 0$ and without loss of generality we normalize $\tau(0) = 1$ and assume that the offshoring cost schedule is sufficiently steep so that $\tau(1) > 2^\theta$. The range of tasks performed offshore is determined by the trade-off between these offshoring costs and the benefits from concentrated task performance through larger scale as well as the disparity of production workers' wages between the two countries.

Let $Q(\mathcal{H})$ denote the Lebesgue-measure of tasks concentrated in the home economy and analogously for tasks concentrated in the foreign country $\mathcal{F}$. Tasks performed domestically by firms in both countries are denoted by $\mathcal{B}$. This allows us to rewrite the marginal cost for a final good in the home and foreign economy, respectively, as

$$c = \frac{wQ(\mathcal{H})}{(nx + n^*x^*)^\theta} + \frac{w^*T(\mathcal{F})}{(nx + n^*x^*)^\theta} + \frac{wQ(\mathcal{B})}{(nx)^\theta} \tag{1.16}$$

$$\text{and} \quad c^* = \frac{wT(\mathcal{H})}{(nx + n^*x^*)^\theta} + \frac{w^*Q(\mathcal{F})}{(nx + n^*x^*)^\theta} + \frac{w^*Q(\mathcal{B})}{(n^*x^*)^\theta}. \tag{1.17}$$

In these expressions $T(\cdot)$ denotes the Lebesgue-measure of tasks augmented by the cost of trade, such that $T(\mathcal{F}) := Q(\mathcal{F}) \int_{i\in\mathcal{F}} \beta t(i)\mathrm{d}i$. In what follows we shall occasionally use $t(\mathcal{F}) := T(\mathcal{F}) - Q(\mathcal{F})$ and analogously for the set of home-concentrated tasks $\mathcal{H}$. The full employment conditions for production labor can now be written as

$$L = \frac{nxQ(\mathcal{H})}{(nx+n^*x^*)^\theta} + \frac{n^*x^*T(\mathcal{H})}{(nx+n^*x^*)^\theta} + \frac{nxQ(\mathcal{B})}{(nx)^\theta} \tag{1.18}$$

$$\text{and} \quad L^* = \frac{nxT(\mathcal{F})}{(nx+n^*x^*)^\theta} + \frac{n^*x^*Q(\mathcal{F})}{(nx+n^*x^*)^\theta} + \frac{n^*x^*Q(\mathcal{B})}{(n^*x^*)^\theta}. \tag{1.19}$$

Note that our scaling assumptions imply $Q(\mathcal{H}) + Q(\mathcal{F}) + Q(\mathcal{B}) = 1$, which allows us to rewrite the marginal cost equations as

$$c = \frac{w}{a}\left[1 + (\alpha - 1)\,Q(\mathcal{H}) + \left(\frac{w^*\alpha}{w} - 1\right) Q(\mathcal{F}) + \frac{w^*\alpha}{w} t(\mathcal{F})\right] \tag{1.20}$$

$$\text{and} \quad c^* = \frac{w^*}{a^*}\left[1 + (\alpha^* - 1)\,Q(\mathcal{F}) + \left(\frac{w\alpha^*}{w^*} - 1\right) Q(\mathcal{H}) + \frac{w\alpha^*}{w^*} t(\mathcal{H})\right]. \tag{1.21}$$

In these expressions, we define labor requirement coefficients $a := (nx)^\theta$, $a^* := (n^*x^*)^\theta$, and $A := (nx + n^*x^*)^\theta$. The productivity of performing non-concentrated tasks relative to concentrated tasks is $\alpha := a/A \leq 1$ and $\alpha^* := a^* \leq 1$.

Obviously, without task trade we have $c = w/a$ and $c^* = w^*/a^*$. Each of the bracketed terms in equations (1.20) and (1.21) is smaller than 1 and represents the cost advantage from task trade. This corresponds to the *productivity effect* in Grossman and Rossi-Hansberg (2008).[12]

In a similar fashion, we may write the full employment conditions as

$$L = \frac{nx}{a}\left[1 + (\alpha - 1)\,Q(\mathcal{H}) + \alpha^{\frac{\theta-1}{\theta}} \alpha^{*\frac{1}{\theta}} \left[Q(\mathcal{H}) + t(\mathcal{H})\right] - Q(\mathcal{F})\right] \tag{1.22}$$

$$\text{and} \quad L^* = \frac{n^*x^*}{a^*}\left[1 + (\alpha^* - 1)\,Q(\mathcal{F}) + \alpha^{*\frac{\theta-1}{\theta}} \alpha^{\frac{1}{\theta}} \left[Q(\mathcal{F}) + t(\mathcal{F})\right] - Q(\mathcal{H})\right]. \tag{1.23}$$

[12] In equation (1.20), the second term in the brackets is negative since $\alpha < 1$, which simply means that concentrated task performance gives a productivity advantage over dispersed performance. The third plus the fourth term may be written as $(w^*\alpha/w)\,T(\mathcal{F}) - Q(\mathcal{F}) < 0$. The explanation for this inequality runs as follows. The term $w^*\alpha/w$ measures the ratio of foreign to domestic cost per unit of task performance, while $Q(\mathcal{F})/T(\mathcal{F}) > 1$ measures the *average* labor requirement of domestic task performance, relative to foreign task performance, which is larger than the same ratio at the margin of $\mathcal{F}$, due to $\tau' > 0$. By the local deviation condition for foreign concentration derived in Grossman and Rossi-Hansberg (2012), the cost ratio $w^*\alpha/w = 1/\left[\beta\tau(I^*)\right]$ is equal to or smaller than the domestic-to-foreign labor requirement ratio at the margin of $\mathcal{F}$. A similar reasoning applies to equation (1.21).

The bracketed terms in these equations may be compared to the *labor supply effect* of offshoring identified by Grossman and Rossi-Hansberg (2008). In their case, since offshoring is one-way with concentration in the foreign economy, the labor supply effect is unambiguously positive for the home economy. In the present case, offshoring is potentially two-way. Hence, the labor supply effect is ambiguous, meaning that the bracketed terms can be smaller or larger than one. The condition for a positive labor supply effect for the home economy can be written as

$$Q(\mathcal{F}) > (\alpha - 1)\, Q(\mathcal{H}) + \alpha^{\frac{\theta-1}{\theta}} \alpha^{*\frac{1}{\theta}} \left[Q(\mathcal{H}) + t(\mathcal{H})\right] \tag{1.24}$$

and equivalently for the foreign economy.[13]

1.3.2 Factor income and the pattern of offshoring

Employing equation (1.2) we can derive total income earned by home managers as

$$sM = \frac{1}{\sigma - 1} \left(wL + \frac{nx}{A} w^* T(\mathcal{F}) - \frac{n^* x^*}{A} w T(\mathcal{H}) \right). \tag{1.25}$$

Note that production and offshoring volumes are all determined endogenously. However, this expression still yields interesting insights into the distributional mechanisms which are summarized in the following proposition.

Proposition 3 (Offshoring and income distribution). If $n^* x^* w T(\mathcal{H}) > n x w^* T(\mathcal{F})$, then $sM/(wL)$ is lower than in an equilibrium with trade only in final goods. An equivalent condition holds for the foreign country.

Proof. See equation (1.25) and a corresponding equation for $s^* M^*$. □

This proposition means that if a country hosts a substantial amount of concentrated tasks while relatively few tasks are concentrated in the other economy, aggregate managerial income relative to worker income in this economy is lower than in an equilibrium with trade only in final goods. We can combine equation (1.25) with a corresponding equation for $s^* M^*$ to obtain

$$sM + s^* M^* = \frac{1}{\sigma - 1} \left(wL + w^* L^* \right), \tag{1.26}$$

[13] A sufficient condition for a positive labor supply effect in the home economy is given by $Q(\mathcal{F}) > \alpha\left[Q(\mathcal{H}) + t(\mathcal{H})\right]$ if $\alpha \geq \alpha^*$ and $Q(\mathcal{F}) > \alpha^* \left[Q(\mathcal{H}) + t(\mathcal{H})\right]$ if $\alpha^* \geq \alpha$. This is proven by $\alpha - 1 < 0$ and $\alpha \geq \alpha^{\frac{\theta-1}{\theta}} \alpha^{*\frac{1}{\theta}}$ for $\alpha \geq \alpha^*$ whereas $\alpha^* \geq \alpha^{\frac{\theta-1}{\theta}} \alpha^{*\frac{1}{\theta}}$ for $\alpha^* \geq \alpha$ and analogously for the foreign economy.

which states that in the presence of offshoring the distribution between managers and workers in the aggregate of the two countries is the same as the one that is obtained for each country individually in an equilibrium where offshoring is ruled out.

To sharpen our focus on an equilibrium with *relative* endowment differences we now impose the condition $nx = n^*x^*$, which neutralizes all size effects on productivity that would otherwise result from variations in relative endowments. Note that the number of firms n and firm size x are both endogenous variables. Hence, to be consistent with the equilibrium conditions introduced above, adding this size-neutrality condition implies endogenous adjustment of a variable that we have so far treated as exogenous. Suppose, for instance, that the relative endowment of the home economy, L/M, is fixed and M^* is fixed as well. Suppose, moreover, that initially the two countries have the same relative endowment and that we now want to make the foreign economy a more production labor abundant economy, in order to explore the effect of asymmetric endowment changes. Given M^*, this implies an exogenous increase in L^*. To ensure that the size-neutrality condition $nx = n^*x^*$ is satisfied factor endowments in the home economy must increase as well, without changing their relative proportion. We can illustrate this adjustment by a scale variable for endowment in the domestic economy, z, and write the relative endowment of the home economy as zL/zM, whereby in the initial equilibrium we have $z = 1$. Given the size-neutrality condition, any exogenous variation in L^* implies an endogenous adjustment in z. The resulting pattern of task trade and wages can be summarized by the following proposition.

Proposition 4 (Task trade with different relative endowments). If the two countries feature different relative endowments, $L^*/L > 1 > M^*/M$, and if $nx = n^*x^*$, we differentiate between two cases. (1) For $\beta \geq 2^\theta$ the equilibrium features $w > w^*$ and one-way task trade, with a concentration of tasks with low offshoring costs in the country with the larger endowment of production labor relative to managerial labor. (2) For $\beta < 2^\theta$ there exist three types of equilibria. (a) If the endowment ratio exceeds a threshold level $L^*/L > \Lambda > 1$ then the equilibrium is as above. (b) For $L^*/L = \Lambda > 1$ production wages are equalized, $w^* = w$, and the task trade pattern is characterized as above. (c) For $1 < L^*/L < \Lambda$ the equilibrium features equalization of production wages, $w^* = w$, whereby the pattern of task trade is indeterminate, as is the managerial wage rate in either country.

Proof. The proof is in the appendix. □

The intuition for case (1) is that full employment of asymmetric endowments in both countries can be reached only if the production labor abundant economy uses part of its workers to perform tasks for the other economy. An equilibrium without trade in tasks is not feasible given asymmetric endowments and our anchoring assumption $nx = n^*x^*$, as can be seen from equations (1.22) and (1.23). For any $\beta \geq 2^\theta$ the scale advantage from concentrated task performance can only make firms indifferent between offshoring and domestic performance of the task with lowest offshoring costs. This means that a wage advantage $w > w^*$ is necessary for profitable concentration of at least some tasks at the lower end of the continuum $i \in [0, 1]$.

Now imagine a $\beta < 2^\theta$. This implies that offshoring of at least some tasks is profitable for equal wages, based on the scale effect alone. Hence, there must exist a value of L^*/L such that offshoring of the well-defined range of tasks below the cutoff determined by $2^\theta = \beta\tau(I^*)$ absorbs the excess production labor of the foreign economy, implying equal wages $w = w^*$. Moving to more asymmetric endowments requires a higher level of offshoring which is conceivable only with unequal wages $w > w^*$. This is case (a) of the proposition. Conversely, moving to less asymmetric endowments requires a smaller range of tasks concentrated in the foreign economy. This necessarily gives rise to two-way task trade with equal wages, described in case (c). No other equilibrium is possible, given the deviation possibilities of firms in the two countries.

1.4 Simulation results

There are two reasons for using simulation methods. First, the model is analytically intractable since the equilibrium depends on integrals over the different sets of tasks which are themselves functions of the model parameters, with a potential of multiple equilibria due to external economies of scale. Perhaps more importantly, numerical simulation allows us to identify likely orders of magnitude and to highlight non-monotonic outcomes. The outcomes we are interested in are inequality within and across countries, as determined by country size and relative endowments in combination with different volumes of offshoring. With offshoring volume we mean the share of tasks concentrated in either of the two countries. Looking at alternative offshoring volumes seems natural, given the focus of the policy debate. Moreover, it allows us to conveniently relate the figures in this section to our analytical results of section 1.2.2. Note that different volumes of offshoring implicitly reflect different values of β, which measures the costliness of trade in tasks. We design all figures below such that the "far south" consistently corresponds to zero levels of offshoring. In addition to allowing for asymmetric relative endowments, our focus on inequality adds a new perspective to the symmetric case with equal relative endowments but differences in total endowments described by Grossman and Rossi-Hansberg (2012).

We choose parameter values so as to ensure comparability with Grossman and Rossi-Hansberg (2012): $\tau(i) = i + 1$, $\theta = 0.8$, $f = 1$, and $\sigma = 2$.[14] First, we look at their *symmetric case*, where relative endowments are equal to one in both countries and world the endowment is fixed at $M + M^* = 2$ and $L + L^* = 2$. Subsequently, we analyze an asymmetric case, where the home economy is abundantly endowed with managers, meaning $M/M^* > 1 > L/L^*$. As discussed at length in the preceding section, we sharpen our focus on *relative endowment asymmetry* by shutting down the country size channel through the assumption $nx = n^*x^*$.

We start by analyzing *inequality between the two countries*. Figure 1.1 looks at the symmetric case with equal relative endowments but differences in aggregate endowments of the two countries, depicting international inequality as defined in equation (1.9) for varying degrees of size advantage as well as varying amounts of offshoring. The figure indicates that external economies of scale for tasks work to the benefit of the large country for all offshoring levels, as expected from equation (1.12). Moreover, the larger (richer) country gains more from incipient offshoring, but less from increments of offshoring at higher levels of integration. The intuition is as follows. Since the larger country hosts tasks with high task-specific offshoring cost, it gains more from incipient task trade than the small country which hosts tasks with lower trade costs. Moreover, the set of tasks concentrated in the large country is larger, implying less spending on transport costs and more efficient production due to the scale effect. However, if the offshoring level is high already, small country producers benefit more than large country producers from a further reduction in trade costs, since their infra-marginal range of imported tasks is larger.

Figure 1.1 only depicts the equilibrium in which the larger country produces a higher aggregate output with higher wages and hosts concentrated performance of tasks with intermediate offshoring costs. However, for parameter values to the south-east of the white

[14] Grossman and Rossi-Hansberg (2012) demonstrate that the choice of $\sigma = 2$ implies that the symmetric case involves offshoring in both directions whenever there is offshoring at all. Moreover, as we show in equation (1.6), it yields equal remuneration for managers and workers in the symmetric case whenever there is no offshoring.

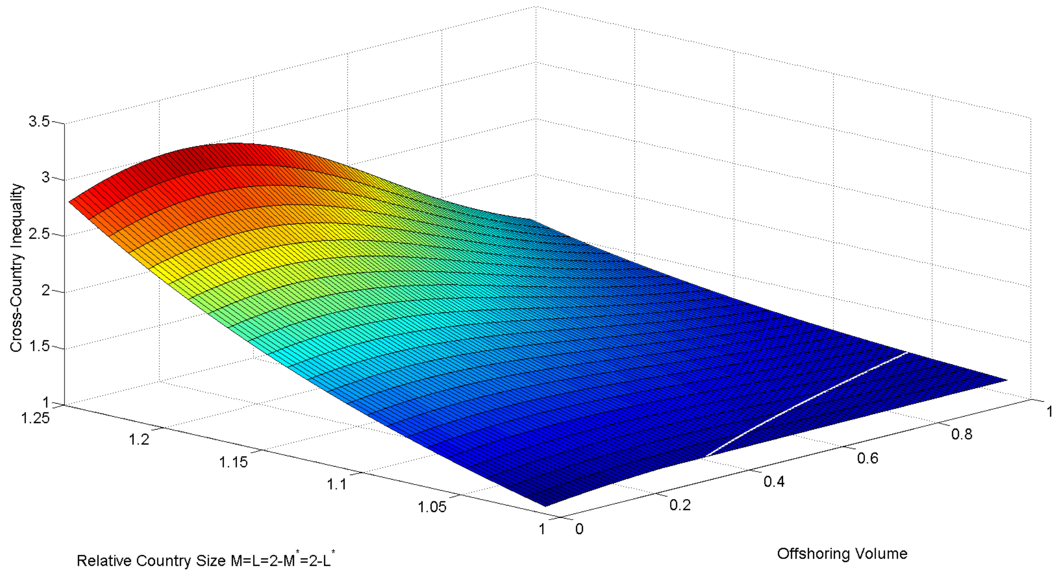

Figure 1.1: Symmetric case: Cross-country inequality

Calibration: $M = L = 2 - M^* = 2 - L^*$ and $Offshoring\,Volume = \mathcal{H} + \mathcal{F}$
$\sigma = 2$, $\theta = 0.8$, $f = 1$

line, where countries are of similar size and offshoring costs are low, two further equilibria can arise. The larger country may end up having a lower aggregate output level, lower wages and producing tasks with relatively low offshoring costs or production wages in the two countries might be equal.[15]

Figure 1.2 highlights the role of relative endowments that are *asymmetric* enough to yield a unique one-way offshoring pattern, excluding the equilibrium described in part (2c) of proposition 4 above, which arises in the south east of the diagram. Again, the south-western edge of the figure corresponds to an equilibrium without offshoring, which generally implies an ambiguous reaction of international inequality with respects to asymmetric endowment changes, depending only on the relationship of $1/\sigma$ and the share of managers in the foreign economy λ_{M^*}. With our choice of parameters, $\sigma = 2$ and $\lambda_{M^*} \leq 1/2$, hence inequality is increasing with the endowment change considered. When the first tasks are concentrated in the worker-abundant economy, it gains from an increase in productivity and wages. This means that cross-country inequality is reduced. However, this pattern is eventually

[15]For a description of such multiple equilibria see the discussion in Grossman and Rossi-Hansberg (2012).

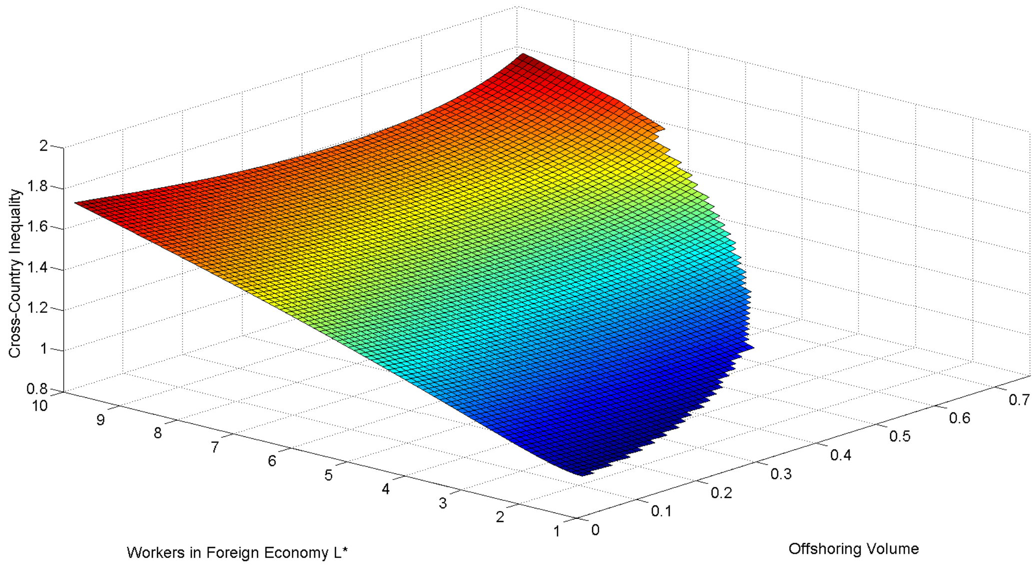

Figure 1.2: Asymmetric case: Cross-country inequality

Calibration: L^* and $Offshoring\,Volume = \mathcal{F}$

$\sigma = 2,\ \theta = 0.8,\ f = 1$

reversed by a further reduction in β, because the manager-abundant country gains from lower offshoring cost on infra-marginal tasks.

Next, we turn to *within-country inequality*, looking at the managerial wage premium. We report results for the home economy, assumed to be relatively large in the symmetric case and manager-abundant in the asymmetric case. In the symmetric case depicted in figure 1.3, initial offshoring drives up the managerial wage premium.[16] This is because managers' salaries move proportionally with output per unit of the fixed manager input, which is an increasing function of the *total* volume of offshoring, whereas production workers only benefit from the increased productivity in tasks concentrated *domestically*. If the home country is larger, a larger share of tasls is concentrated there so that workers benefit almost as much as managers, and the increase in the managerial wage premium is less pronounced; see the south-west in the diagram. With zero total offshoring, changes in country size cannot change the location of any task so that all effects on the wage premium vanish, as shown analytically in equation (1.6). Interestingly, for very high offshoring levels, further reductions in the costs of task trade lead to a fall in the managerial wage premium. This is due to the different

[16] As above, in figure 1.3 the parameter combinations for which a second equilibrium with higher wages in the small country might occur is separated, to the north-east, by a white line.

deviation conditions governing the location of tasks. The highest managerial wage premium is characterized by equality of the local and global deviation conditions for domestic firms. For higher offshoring volumes, the task that separates the sets of tasks concentrated in the home and foreign economy is determined by the global deviation condition, increasing the set of tasks concentrated in the home economy and yielding a higher demand for home production workers which drives up their wages.[17]

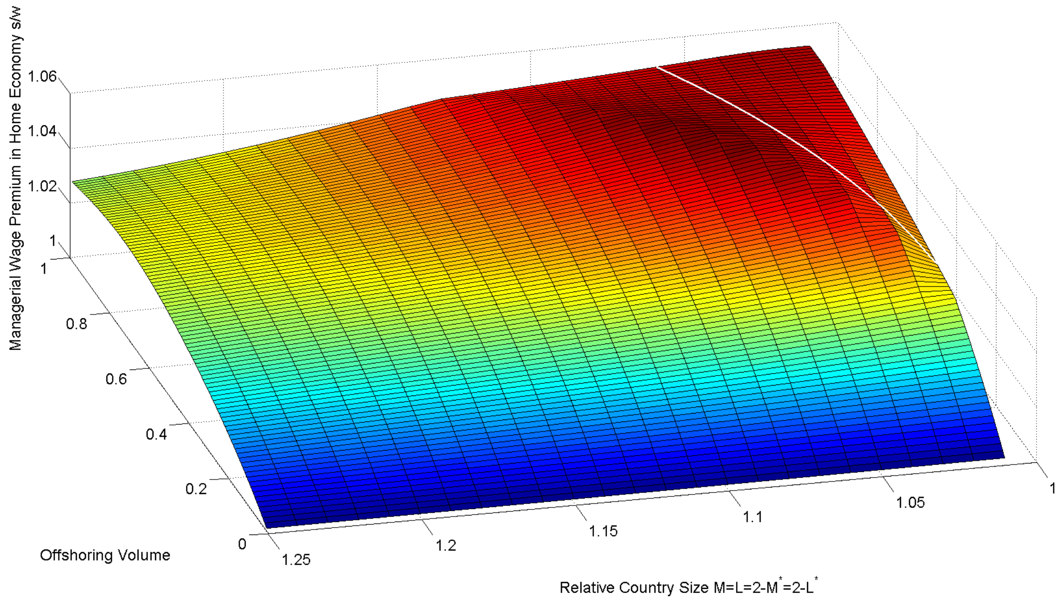

Figure 1.3: Symmetric case: Within-country inequality

Calibration: $M = L = 2 - M^* = 2 - L^*$ and $Offshoring\,Volume = \mathcal{H} + \mathcal{F}$
$\sigma = 2,\ \theta = 0.8,\ f = 1$

In the asymmetric case (not shown for lack of space) we can identify a very simple pattern of the income distribution in the manager-abundant country. A rising level of offshoring drives up the managerial wage premium, since home managers benefit from the increased productivity of their firms due to the offshoring possibility, whereas production workers do not experience a higher productivity. Comparing the symmetric with the asymmetric case, we see that the move from no offshoring to a high level of offshoring can increase the managerial premium by a factor of around 3.5 in the latter, whereas it only rises by a factor of 1.05 in the latter. Considering developing countries to be relatively production labor-abundant, this result is very much in line with the stylized empirical facts mentioned

[17]Also see the discussion in Grossman and Rossi-Hansberg (2012) about global and local deviation.

in the introduction, and it confirms our view that this model is able to contribute to our understanding of these trends in income distribution.

1.5 Conclusion

In this paper, we have argued that wage and inequality effects of trade should be addressed by focusing on the distinction between managerial and production workers, where managerial labor is a fixed input in production, while production work serves as a variable input. A key tenet of our analysis is that this asymmetry importantly shapes the determination of managerial salaries and production wages. A second fundamental assumption underlying our analysis is that production-labor often benefits from local spill-over effects related to narrowly defined tasks along complex value added chains, and that modern technology of communication and transport increasingly makes such tasks tradable.

We have used a 2-country model of task trade recently developed by Grossman and Rossi-Hansberg (2012), which we have extended to the case of asymmetric labor endowment. We have first presented a number of analytical results. For instance, in a world without trade in tasks, we can neatly identify three different channels through which country endowments affect international inequality: There is a terms-of-trade effect, but also a productivity effect of countries becoming larger. In addition, there is a composition effect if endowments change in an asymmetric fashion.

Introducing the possibility of trade in tasks between asymmetric countries, we have shown that it is often one-way in nature, provided that the two countries' relative endowments are sufficiently asymmetric. In such an equilibrium the production worker-abundant economy exports task performance against imports of differentiated final goods, and it has a lower production wage than the manager-abundant economy.

We have complemented these analytical results by numerical simulations. An interesting non-monotonicity arises for international inequality between differently sized countries that are symmetrically endowed with managers and workers. Starting out from low levels of offshoring, a reduction in the cost of task trade generates gains mainly for the large country, while the opposite is true once these cost fall below a certain threshold value. A similar non-monotonicity arises in the asymmetric case, where for low levels of offshoring it is the country with more production workers that reaps the bulk of globalization gains, while manager-abundant economies benefit once globalization has gone sufficiently far. Our simulation results are in line with the known facts relating to the wage premium for non-production over production workers in the US.

Chapter 2

Trading Tasks: A Dynamic Theory of Offshoring*

2.1 Introduction

In this paper I analyze the implications of imitation risk for firms' offshoring decisions. Following Grossman and Rossi-Hansberg (2008), in my model production can be sliced into a continuum of tasks but iceberg offshoring costs are homogenous. Heterogeneity of tasks results from the information that tasks contain about the final product, which facilitates imitation whenever a task is performed offshore. Logically, tasks containing less information are offshored first, so that each additional task that is offshored results in an overproportional increase of the imitation risk. Trading off savings on production costs with the imitation risk, northern firms determine the optimal level of offshoring.

The structure of the model allows me to estimate perceived imitation rates that are consistent with changes in offshoring intensity and relative unit labor costs between developed countries and China between 1990 and 2011. Using just a marginal share of intermediate inputs from China implies a baseline imitation probability between 6 per cent and 12 per cent, depending on the specification of the estimation. When imports of intermediate inputs from China account for 20 per cent of local manufacturing value added, as observed for Korea in 2008, the implied imitation probability rises to levels between 15 per cent and 30

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per cent. These estimates correspond to substantial mark-ups that firms are willing to pay to domestic workers for not having to use offshore production.

The quantitative importance of imitation risk for firms' offshoring decision has so far only been analyzed in surveys. Among 94 major US firms, Mansfield (1994) finds that the decision to conduct foreign direct investment (FDI) to manufacture components and to manufacture complete products was said to be strongly influenced by intellectual property rights (IPR) protection in 49 and 58 per cent of the cases, respectively. Very similar results were found in a survey among German and Japanese firms by Mansfield (1995). A larger literature studies the qualitative impact of IPR legislation on the international activity of multinational enterprises (MNEs). Amongst others, Branstetter et al. (2006, 2011), Canals and Sener (2011), and Naghavi et al. (2013) find that better IPR protection is key for attracting investment.

Given this relevance of imitation risk for firms' offshoring decision, I then present a dynamic product cycle model with offshoring and imitation.[1] In this setup I analyze the impact of an exogenous reduction of technological offshoring costs on the level of offshoring, differentiating between a short-run and a long-run analysis. In the short run, the composition of northern and southern varieties is assumed to remain constant. A reduction of offshoring costs induces firms to intensify their offshore activity, accepting a higher imitation risk in return for higher savings on production costs. This implies a sharp increase in the offshoring volume.

The long run, however, is characterized by an adjustment of the variety composition to its new steady-state. Since the imitation rate has been driven up by a rising level of offshoring, the steady-condition of equal growth rates of all varieties requires that a higher share of varieties is produced in the South. As the variety composition adjusts towards the steady state, the wage gap of production workers between the two countries is gradually reduced. This implies a gradual deterioration of production cost savings from offshoring so that northern firms optimally adjust their offshoring volume to a lower level, but still higher than in the initial steady state. In other words, exogenous reductions in technological offshoring

[1] Imitation means that there is an endogenous probability of losing all future profit when the production is taken over by a southern firm at a lower cost. Vernon's (1966) idea of the product cycle was formalized later on by Grossman and Helpman (1991a) in a variety expansion model and by Segerstrom et al. (1990) in a quality ladder model. Other important contributions, subsequently introducing FDI and making the imitation decision endogenous are Helpman (1993), Lai (1998), Glass and Saggi (2002), and Branstetter and Saggi (2009). The literature mostly discusses the impact of FDI and intellectual property rights on the rate of innovation.

costs imply an overshooting in the increase of the offshoring volume and a subsequent reduction of offshoring on the transition path to the new steady state. Consequently, this model is consistent with evidence that companies from developed countries have increasingly been active in reducing offshore activity and instead bringing some of their production back to the domestic economy in a time where improvements to offshoring technology seem to have slowed down. A phenomenon called "backshoring" or "reshoring" in the media and business literature, see e.g. Economist (2013), Hagerty (2013), Maher and Tita (2010), and Simchi-Levi et al. (2011).

In a last step I consider the impact of offshoring on relative wages. In addition to the productivity effect and labor supply effect of offshoring, well-known from Grossman and Rossi-Hansberg (2008), there is a short-run intertemporal profit effect to the benefit of low-skilled workers and a long-run composition effect to the benefit of high-skilled workers.[2] Both of these effects are induced by endogenous changes of the imitation rate. However, whereas the intertemporal profit effect depends immediately on the imitation rate, the composition effect is induced by the subsequent adjustment of the variety composition between North and South. In the long run, the composition effect always dominates the intertemporal profit effect. This pattern implies that the endogenous adjustment of the imitation rate benefits low-skilled workers in the short run, compared to a model in which offshoring has no impact on imitation, whereas it benefits high-skilled workers in the long run.

This expands our understanding of the effect of offshoring on wages of different types of workers beyond the results from Grossman and Rossi-Hansberg (2008). The effect does not only depend on the initial offshoring intensity and the shape of the offshoring cost function, but also on the underlying technology shock that induces changes in offshoring in the first place. This is especially true in the short run when the economy has not yet converged to its steady state. Given that different industries in different periods of time are characterized by different patterns of technology shocks it can be difficult to empirically identify a meaningful unambiguous correlation between offshoring volume and skill premium.[3]

[2]My model does not feature a relative price effect since I focus on a one-sector economy for the sake of simplicity.

[3]On the industry-level, Feenstra and Hanson (1999) estimate that offshoring explains about 15% of the increasing relative wage of nonproduction workers in the US. Geishecker (2006) finds that offshoring to Central and Eastern Europe is responsible for half of the wage increase of German high-skilled workers, while Hsieh and Woo (2005) find roughly the same importance of offshoring to China for high-skilled workers' wages in Hong Kong. Yan (2006) finds a positive impact of offshoring on wages of high-skilled workers in Canada. Studies on the plant level include Verhoogen (2008) on Mexico, Amiti and Davis (2011) on Indonesia, and

This paper adds to the list of theoretical articles on the international fragmentation of production chains, also called offshoring.[4] Models of offshoring usually require that production be sliced into tiny components or tasks that are heterogeneous with respect to their skill intensity or offshoring costs. Just to mention some important contributions, Feenstra and Hanson (1997) present a one-sector model with a continuum of inputs and show that offshoring may increase skill premia in both countries that engage in bilateral offshoring. Arndt (1997) uses a two-sector framework to demonstrate that workers may gain, even if labor-intensive activities are offshored. Trefler and Zhu (2005) point to a systematic effect towards a rising skill premium when developing countries' raise their income. Grossman and Rossi-Hansberg (2008) decompose the effect of offshoring on wages into productivity effect, labor-supply effect, and relative-price effect.[5] In general, the effects of offshoring on wages are quite different from the effects of trade in final products.[6]

Few other papers have been looking at the interaction of offshoring and research activity. Most notably, Acemoglu et al. (2012) study the long-run and short-run consequences of offshoring in a model with technical change. They find that offshoring and technical change are substitutes in the short run but complements in the long run. The impact of offshoring on skill inequality is largest at low levels of offshoring. Rodríguez-Clare (2010) explores the role of innovation on the welfare implications of offshoring. Assuming a fixed level of offshoring, he finds that dynamic gains from enhanced innovation can potentially compensate for static losses in the northern country. Earlier, Glass and Saggi (2001) show in a quality-ladder model that a reduction of offshoring costs can lead to an increase in the rate of innovation in the North, when it is accompanied by lower wages. Glass (2004) introduces an imitation channel in the southern country that constitutes an increase in the cost of adapting a certain innovation to foreign sourcing. Naghavi and Ottaviano (2009) emphasize difficulties in the communication between researchers and production workers in offshore production, which

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Hummels et al. (2011) on Denmark. Crinò (2010) and Liu and Trefler (2011) analyze the effects of service offshoring in the United States.

[4]Empirical evidence on the magnitude and growth of offshoring can be found in Hummels et al. (2001), Yeats (2001), and Yi (2003).

[5]Other contributions include Venables (1999), Egger and Falkinger (2003), Kohler (2004), Egger and Kreickemeier (2005), Antràs et al. (2006), Grossman and Rossi-Hansberg (2012), and Markusen (2013).

[6]It is well-known that the crucial role played by a country's endowments for its factor prices is reduced when countries open up to trade. Indeed, the factor price equalization theorem states that under certain conditions all countries' factor prices are determined by the world endowment. Accordingly, trade does away with premia earned by the owners of a country's scarce resources, and the factor content of trade should tell us what openness does to a country's factor prices. See the discussion in Deardorff (2000), Krugman (2000), Leamer (2000), and Panagariya (2000).

may lead to welfare losses if the offshoring decision fails to internalize the negative effect on research productivity.[7] All of these papers have in common a focus on the steady state properties, whereas they mostly neglect transitional dynamics, which are a major point of interest of this paper.

The paper is structured as follows. Section 2.2 presents the offshoring optimization in a static model. Section 2.3 estimates the perceived imitation risk comprised in firms' offshoring decisions. Section 2.4 outlines the dynamic product cycle model with offshoring. Section 2.5 explains the dynamic adjustment of the offshoring intensity. Section 2.6 presents the effects on relative wages on the transition path of adjustment. Section 2.7 concludes.

2.2 A static model of offshoring and imitation

The model comprises two countries, North and South. All variables referring to the South are indicated by an asterisk. Each country is home to a fixed number of consumers L and L^*, of which a fraction, h and h^*, are highly skilled and thus a fraction, $1-h$ and $1-h^*$, are of the low-skilled type. All consumers supply one unit of their respective type of labor inelastically. Low-skilled labor is used in the manufacturing sector, while high-skilled workers are employed only in the research sector, but the static model in this section is silent about the role of high-skilled workers.

2.2.1 Manufacturing sector

There exists a number of varieties n produced in the North and a number of varieties n^* produced in the South. The total number of varieties is $N = n + n^*$. Production of each variety is divided into a continuum of tasks with index i defined on the unit interval $i \in [0; 1]$. To produce one unit of the final consumption good, each task must be performed exactly once. Production tasks are exclusively performed by low-skilled workers.[8] I assume that wages for low-skilled workers in the South are lower than those for low-skilled workers in the North. This implies that northern firms can have tasks performed offshore in the South, benefiting

[7] Another mentionable paper is Lai et al. (2009), in which offshoring is part of the innovative activity itself. Consequently, the contract that is written with an R&D subcontractor needs to take into account the leakage of knowledge to the South.

[8] One might argue that high-skilled workers could always pretend to be low-skilled and also perform production tasks. However, there is no incentive to do so if the parameters of the model are plausibly chosen so that high-skilled workers' salary is higher than low-skilled workers' wage, $s \geq w$.

from lower production wages. However, offshore production conveys iceberg transport costs τ for each task performed offshore. I will focus on scenarios with a strictly positive offshoring volume so that $w > w^*\tau$.

In addition, offshoring implies an increase in the risk of imitation. The reason is that each task contains a certain amount of knowledge about the final variety. The more of this knowledge is revealed to the South via offshoring, the easier is imitation. Production tasks differ with respect to the knowledge they can transmit to the South via offshoring, indicated by an imitation risk function $\mu(i)$. Without loss of generality I can order tasks from 0 to 1 such that the knowledge contained in each task rises strictly monotonically in i. This implies that $\mu(0) \geq 0$, $\mu(i) \geq 0 \, \forall \, i$, and $\mu'(i) > 0$, so that imitation is more likely if the share of offshore provided tasks is high and that the increase in the likeliness of imitation is higher the higher is the offshoring volume.

Because expensive northern workers are replaced by cheap southern workers, offshore production implies savings on production costs, which depend upon the volume of tasks performed offshore and wages in the two countries. I denote this production cost savings factor by $\Theta(I, w, w^*)$, where I is the marginal tasks so that all tasks $[0; I]$ are offshored. Since production costs without offshoring are simply given by w, while production costs with a share I of offshored tasks are given by $w^*\tau I + w(1 - I)$, I define

$$\Theta(I, w, w^*) := \frac{w^*}{w}\tau I + 1 - I. \tag{2.1}$$

Lemma 1. The offshoring savings factor $\Theta(I, w, w^*)$ is always smaller than one, whenever the offshoring volume is strictly positive.

Proof. Given the imitation risk of offshore production, profit-maximizing firms only choose a strictly positive offshoring volume when they are compensated by lower production costs, so that $\tau w^*/w < 1$. This directly implies that $\Theta(I, w, w^*) < 1$. □

Since northern low-skilled workers only perform a fraction $1 - I$ of tasks domestically their full employment condition is given by

$$(1 - h)L = nx(1 - I), \tag{2.2}$$

where x is the output of each northern variety. Demand for consumption goods is characterized by monopolistic competition with an elasticity of substitution σ between varieties. Hence, firms charge a constant markup over production costs. The price charged by northern firms is given by $p = w\Theta(I, w, w^*)\sigma/(\sigma - 1)$ and their profits are

$$\pi = (p - w\Theta(I, w, w^*))x = \frac{w\Theta(I, w, w^*)x}{\sigma - 1} \tag{2.3}$$

where x is still endogenous, depending on w and $\Theta(I, w, w^*)$. In the static model I simply assume that profits are distributed equally among high-skilled workers in each country. Consequently, this implies that the salary of northern high-skilled workers

$$s = \frac{n\pi}{hL} \tag{2.4}$$

increases with the number of northern varieties n and the profits per variety π and decreases with the number of high-skilled workers in the North hL.

For southern firms it is not profitable to use offshoring, but southern low skilled workers can work in offshore manufacturing for the North. Hence, their full employment condition is given by

$$(1 - h^*)L^* = nx\tau I + n^*x^* \tag{2.5}$$

where the first term on the right-hand side represents labor used for northern offshore production while the second term is labor in southern production. The production cost of one unit of the southern variety is w^*, profits of southern firms are given by

$$\pi^* = (p^* - w^*)x^* = \frac{w^*x^*}{\sigma - 1}, \tag{2.6}$$

and the salary of southern high-skilled workers can be written as

$$s^* = \frac{n^*\pi^*}{h^*L^*}. \tag{2.7}$$

Assuming that final goods can be transported costlessly, relative demand for varieties from the two countries only depends on relative prices so that

$$\frac{x}{x^*} = \left(\frac{p}{p^*}\right)^{-\sigma} = \left(\frac{w\Theta(I, w, w^*)}{w^*}\right)^{-\sigma}, \tag{2.8}$$

while relative profits are given by

$$\frac{\pi}{\pi^*} = \left(\frac{w\Theta(I, w, w^*)}{w^*}\right)^{1-\sigma}. \tag{2.9}$$

2.2.2 Offshoring decision

Imitation means that all future profits from producing a variety are lost with a probability m in each period. Firms acknowledge that offshoring drives up the risk of imitation. The marginal increase in the risk of imitation at each level of offshoring is indicated by $\mu(i)\bar{\mu}$, where $\bar{\mu}$ is a constant that does not depend on offshoring but only on the imitation potential of the imitating country. Even though imitation only targets one variety, the ex ante probability of imitation is equal for all varieties, leading to identical choices of offshoring intensity of all firms. Firms discount future profits with the risk-free interest rate R and account for the imitation threat so that the value of a northern firm is given by $v = \pi/(R + m)$. Choosing the offshoring level that maximizes the firm value yields a first order condition

$$\frac{\partial\pi/\partial I}{\pi} = \frac{\partial m/\partial I}{R + m} \tag{2.10}$$

which can be written as

$$\frac{(\sigma - 1)(w - \tau w^*)}{w(1 - I) + w^*\tau I} = \frac{\mu(I)\bar{\mu}}{R + m} \tag{2.11}$$

and characterizes the point where relative changes in profits induced by offshoring and relative changes in firms' discount factor induced by offshoring are equal. However, this point can only be a maximum if firms indeed find it profitable to choose a higher offshoring level when $i < I$ and a lower offshoring level when $i > I$. This requires

$$\frac{(\sigma - 1)(w - \tau w^*)}{w(1 - i) + w^*\tau i} > \frac{\mu(i)\bar{\mu}}{R + m} \quad \forall i < I \tag{2.12}$$

while

$$\frac{(\sigma - 1)(w - \tau w^*)}{w(1 - i) + w^*\tau i} < \frac{\mu(i)\bar{\mu}}{(R + m)} \quad \forall i > I. \tag{2.13}$$

Expressed differently, the second order condition for optimality implies that the slope of the left-hand side of equation (2.11) is smaller than the slope of the right-hand side. Graphically, the two curves are shown in figure 2.1. Mathematically, the second order condition is given

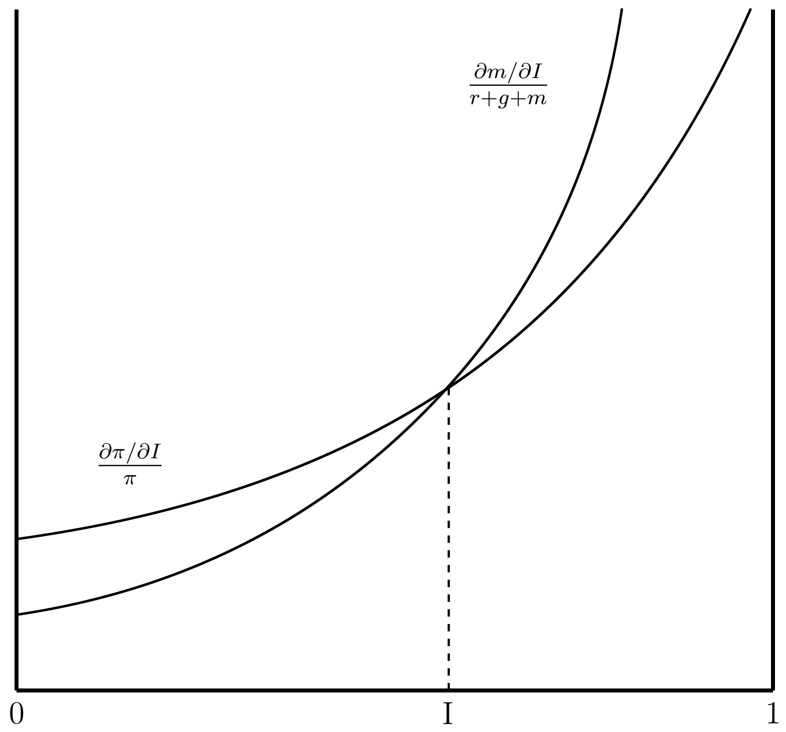

Figure 2.1: Marginal profits and marginal mitation risk.

by

$$\mu'(I)(R+m)(\sigma-1) > \sigma\mu(I)^2\bar{\mu}, \tag{2.14}$$

which implies a lower threshold for the slope of the imitation risk function. Rewriting the first order condition as

$$w - \tau w^* = \frac{w(1-I) + w^*\tau I}{(\sigma-1)(R+m)}\mu(I)\bar{\mu}, \tag{2.15}$$

makes clear that the cost gap between domestic and foreign production is equal to the product of the net present value of profits from selling one unit of output and the marginal effect of offshoring on imitation at the marginal task. It is now possible to solve for the relative cost of any task in North and South as

$$\frac{w}{\tau w^*} = \frac{(\sigma-1)(R+m) + I\mu(I)\bar{\mu}}{(\sigma-1)(R+m) - (1-I)\mu(I)\bar{\mu}} := \nu(I), \tag{2.16}$$

and I define the ratio of domestic to foreign wages inclusive of iceberg offshoring costs as a measure of long-run offshoring costs $\nu(I)$. If firms are only lived for one period but face an offshoring cost function $\tau\nu(i)$ they choose the same level of offshoring I as when they are infinitely lived, facing iceberg offshoring costs τ and an imitation risk function $\mu(i)$. Relative wages must always be positive, so that

$$(\sigma - 1)(R + m) - (1 - i)\mu(i)\bar{\mu} > 0 \quad \forall\, i. \tag{2.17}$$

Lemma 2 (Static stability). The long-run offshoring cost curve $\nu(i)$ is upward sloping in i. This implies that a unique and stable offshoring equilibrium exists.

Proof. The derivative of $\nu(i)$ with respect to i is given by

$$\frac{\mathsf{d}\nu(i)}{\mathsf{d}i} = \frac{\mu'(i)\bar{\mu}(\sigma - 1)(R + m) - \sigma\mu(i)^2\bar{\mu}^2}{\Big((\sigma - 1)(R + m) - (1 - i)\mu(i)\bar{\mu}\Big)^2} > 0, \tag{2.18}$$

which has a positive denominator due to the fact that offshoring costs must be positive as shown in equation (2.17) and the numerator is positive due to the second order condition for optimality in equation (2.14). □

Graphically, the product of iceberg offshoring costs and the long-run offshoring cost schedule $\tau\nu(i)$ crosses the relative wage line w/w^* from below at a uniquely determined marginal task of offshoring I, meaning that northern firms offshore all tasks below I to the South while all tasks above I are performed domestically in the northern economy. The marginal offshoring task is shown in figure 2.2. It is now possible to eliminate relative wages from the offshoring savings factor and write

$$\Theta(I) = \frac{(\sigma - 1)(R + m)}{(\sigma - 1)(R + m) + I\mu(I)\bar{\mu}}. \tag{2.19}$$

Intuitively, a higher volume of offshoring leads to higher savings on production costs and higher profits. This is indicated by a lower $\Theta(I)$.

Lemma 3. The offshoring savings factor $\Theta(I)$ falls with a rising offshoring volume $\Theta'(I) < 0$.

Proof. The derivative of $\Theta(I)$ with respect to I is given by

$$\frac{\mathsf{d}\Theta(I)}{\mathsf{d}I} = \frac{(\sigma - 1)\mu(I)^2\bar{\mu}^2 I - (\sigma - 1)(R + m)\Big(\mu'(I)I + \mu(I)\Big)\bar{\mu}}{\Big((\sigma - 1)(R + m) + \mu(I)\bar{\mu}I\Big)^2} \tag{2.20}$$

which is negative due to the second order condition for optimality in equation (2.14). □

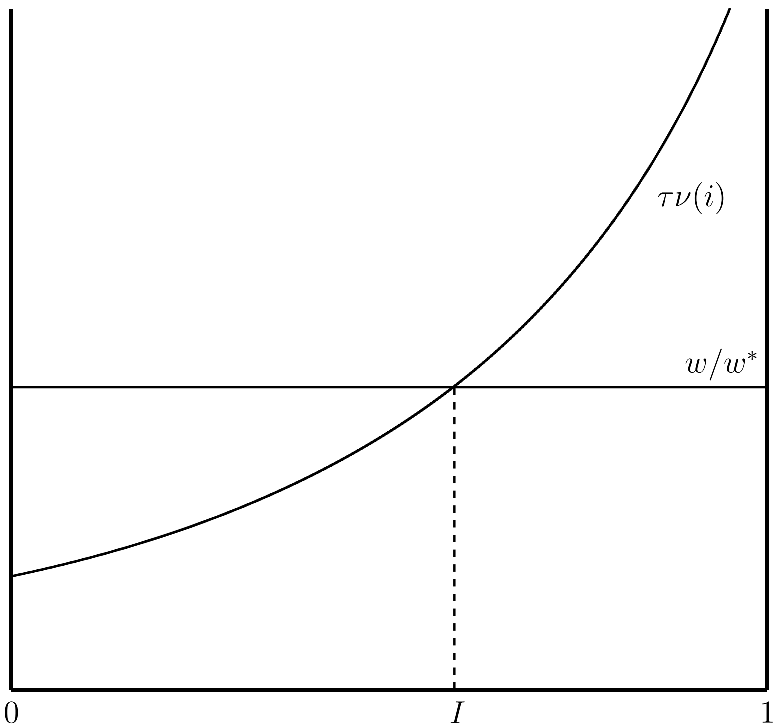

Figure 2.2: Total offshoring cost schedule

2.2.3 Closing the static model

Utility U in the North is given by

$$U = \left(\int_0^N x_k^{\frac{\sigma-1}{\sigma}} \mathsf{d}k \right)^{\frac{\sigma}{\sigma-1}}, \tag{2.21}$$

which implies a Marshallian demand function for each variety k

$$x_k = \frac{E(t) p_k^{-\sigma}}{\int_0^N p_k^{1-\sigma} \mathsf{d}k} := \frac{E p_k(t)^{-\sigma}}{P}, \tag{2.22}$$

where P in the denominator is the well-known Dixit-Stiglitz price index. An analogous relationship holds for the South. Balanced trade implies that income is equal to expenditure in each country so that in the North

$$E = w(1-h)L + shL = pnx - I\tau w^* nx, \tag{2.23}$$

and in the South

$$E^* = w^*(1-h^*)L^* + s^*h^*L^* = p^*n^*x^* + I\tau w^*nx. \tag{2.24}$$

In equilibrium, exports from the North of the South are given by

$$X = \frac{(pnx - I\tau w^*nx)p^*n^*x^*}{pnx + p^*n^*x^*}, \tag{2.25}$$

while northern imports of final goods from the South are given by

$$M = \frac{(p^*n^*x^* + I\tau w^*nx)pnx}{pnx + p^*n^*x^*}, \tag{2.26}$$

so that the export surplus of the North in final goods

$$X - M = I\tau w^*nx \tag{2.27}$$

equals the imports of intermediate inputs.

2.3 Quantification of imitation risk

The structure of the model allows me to quantify the importance of imitation risk in firms' offshoring decision. Specifically, in light of the ongoing discussion about infringement of intellectual property rights in China and accounting for the importance of the country as a manufacturer of intermediate inputs I estimate the risk of imitation that firms perceive when using intermediate inputs from China. I do this by estimating equation (2.16), which characterizes the relative wage of the northern and southern economy as a function of iceberg offshoring costs and the imitation risk. The estimation requires to impose a structure on the functional form of the imitation risk function $\mu(i)$. I assume that it is an upward sloping exponential function

$$\mu(i) = \alpha\, exp(\beta\, i), \tag{2.28}$$

where α determines the base imitation risk when no offshoring takes place and β characterizes the speed with which the imitation risk increases when intensifying the use of offshore production.

I perform the same estimation with four different measures of offshoring intensity. They result from two different measures for the offshoring volume and two different measures for the volume of domestic production. In my preferred specification, the offshoring measure is given by data on OECD countries' imports of intermediate inputs from China. Data on Chinese exports of intermediate inputs to OECD countries are the second offshoring measure.

My preferred measure for domestic production is the value of manufacturing value added in each country. It accounts for the fact that offshoring features much more prominently in the manufacturing sector than in services. Moreover, it adopts the concept of the two theoretical two-country model in which the importance of offshoring is measured by offshore provided tasks relative to tasks performed domestically. The second measure for the value of production is simply GDP.

All descriptive statistics and results reported in this section refer to my preferred measure of offshoring intensity, the value of a country's imports of intermediate products from China over the value of a country's manufacturing value added. For this measure, I have data for 28 OECD countries during a period of 22 years between 1990 and 2011. The data are available for most country-year combinations, summing to a total of 506 observations.[9] Estimation results for the other three combinations are reported as robustness checks in tables B.1 to B.3 in the appendix. Those estimation results are very similar to the results reported in this section.

All data on the volume of intermediate goods trade, on unit labor costs, and on GDP are from the OECD. Data on the share of manufacturing value added of GDP are from the Worldbank. Figure 2.3 shows that Chinese intermediate inputs are small relative to local manufacturing value added. For roughly 58 per cent of all country-year-combinations, the ratio of Chinese inputs to domestic manufacturing value added is smaller than two per cent. For 83 per cent it is smaller than five per cent. Only Korea and some small European economies show a level of Chinese offshoring importance that is higher than ten per cent. Given that manufacturing value added is by definition smaller than GDP, the distribution for my alternative measure of offshoring intensity is even more piled at very small levels of offshoring intensity.

[9]The countries are Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, United Kingdom, and United States.

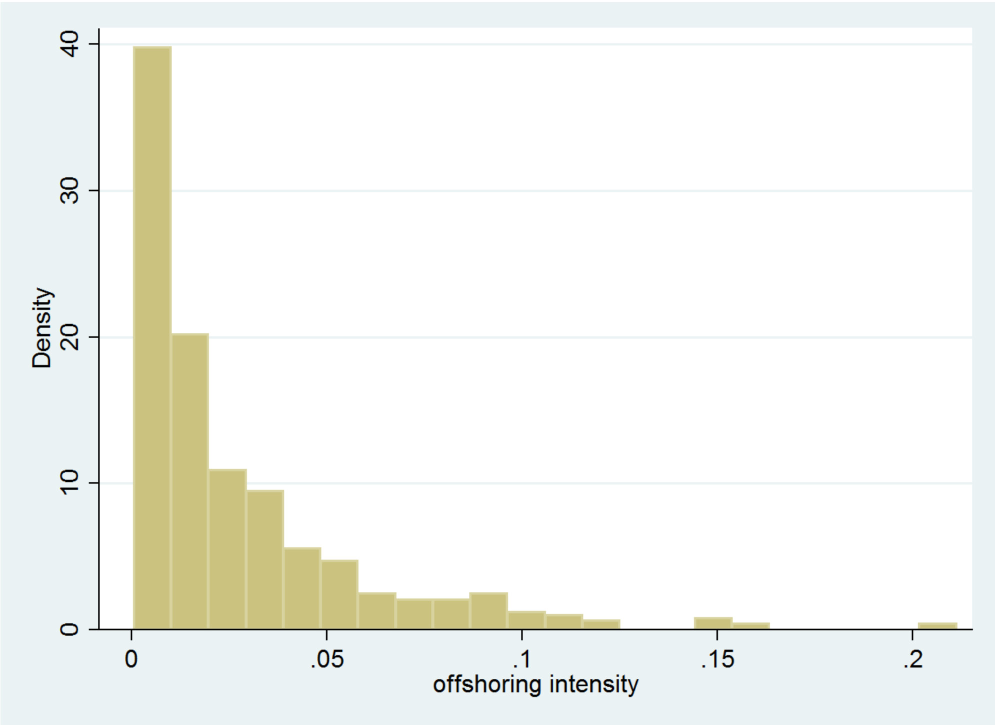

Figure 2.3: Distribution of offshoring intensity.

The equation that I estimate can be written as

$$ulc_{jt} = log\left(\frac{(\sigma-1)(R+\frac{\alpha}{\beta}exp(\beta\, f_{jt})) + f_{jt}\,\alpha\, exp(\beta\, f_{jt})}{(\sigma-1)(R+\frac{\alpha}{\beta}exp(\beta\, f_{jt})) - (1-f_{jt})\,\alpha\, exp(\beta\, f_{jt})}\right) + e_t + e_j + u_{jt} \qquad (2.29)$$

where ulc_{jt} is the log of unit labor cost in country j at time t, f_{jt} measures offshoring intensity with China as the ratio of Chinese exports of intermediate inputs to country j at time t to manufacturing value added of country j at time t. e_t is a year fixed effect that accounts for characteristics that are identical to all partner countries but may vary over time. Most importantly, this fixed effect neutralizes the effect of changes in Chinese unit labor cost. This implies that my regression can identify the relationship between changes in offshoring intensity and changes in the ratio between a countries unit-labor costs and unit-labor costs in China. Moreover, this fixed effect captures all changes in transport or communication technology that have facilitated offshoring and thus may have contributed to closing the gap in unit-labor costs between developed countries and China. e_j is a country fixed effect that accounts for all country-specific characteristics that are constant over time and may influence the gap in unit-labor cost between a country and China. Specifically, this fixed effect captures the impact of distance or cultural ties on the cost of transport or the ease of communication. Under the assumption that there is no other mechanism that leads to a correlation of changes in relative unit labor costs and changes in the offshoring volume this allows me to consistently estimate the parameters of the function $\mu(i)$ and to back out the implies imitation risk for every level of offshoring intensity.

However, this assumption may possibly be violated. During the last years there have been many attempts to classify the tasks that are required in a production process according to their "offshorability", a measure for how easy it is to perform a specific task abroad. Leamer and Storper (2001) attributed a high degree of offshorability to tasks that require codifiable information, whereas tasks which require tacit information are harder to offshore. Autor et al. (2003) and Levy and Murnane (2004) argue that more routine tasks exhibit a higher degree of offshorability. Blinder (2006) reckons that the need for physical contact when delivering the output of a task is crucial for its offshorability. Summarizing, there may be reasons why some tasks are performed offshore even if the wage gap between the domestic and the foreign economy is relatively small, while offshoring other tasks is only profitable with a larger wage gap. Consequently, for any given wage gap, all tasks with a high degree of offshorability will be performed abroad, while those with a low degree of offshorability will be remain in the domestic economy. With a larger wage gap offshoring is profitable for more tasks, implying a positive relationship between wage gap and offshoring intensity. To account for this mechanism and to control for such a correlation, I include the degree of offshoring intensity and its higher order terms as control variables in my estimation. These terms should capture the effect of offshoring intensity on the wage gap between an OECD country and China that results from offshoring costs that are not constant over the entire set of tasks.

The estimation results are reported in table 2.1. Since the results depend on the values of the elasticity of substition σ and the risk free interest rate R, which cannot be estimated simultaneously from the same equation, I report estimated results for various combinations of these parameters. The estimated coefficients for α and β are always positive and strongly significant. In column 1, for relatively low values of σ and R the estimated coefficients are relatively low as well. The reasons is that small changes in the imitation risk already have big effects on the savings in production workers' wages that firms demand for producing offshore, denoted by $\nu(i)$ in the theoretical model. Directly introducing the level of offshoring intensity and its higher order terms has no big effect on the estimated coefficients for α and

β. Moreover, the estimated coefficients for the control variables are not significantly different from zero. This suggest that the special structure of the imitation risk term better captures the prevailing pattern of gaps in unit labor cost between developed countries and China. In other words, imitation risk may be a more dominant driver of intermediate goods trade with China than other explanations for potential nonlinear relationships between offshoring levels and offshoring costs.

Table 2.1: Estimation results: Import data over manufacturing value added

	$\sigma = 3.8$, $R = 0.05$		$\sigma = 3.8$, $R = 0.1$		$\sigma = 5$, $R = 0.05$		$\sigma = 5$, $R = 0.1$	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
alpha	0.34***	0.27***	0.68***	0.54***	0.55***	0.39***	1.09***	0.77***
	(0.01)	(0.02)	(0.03)	(0.04)	(0.03)	(0.04)	(0.06)	(0.07)
beta	3.94***	4.46***	3.94***	4.46***	5.05***	5.79***	5.05***	5.79***
	(0.05)	(0.16)	(0.05)	(0.16)	(0.08)	(0.23)	(0.08)	(0.23)
$ln\ of$		-2.28		-2.28		-2.37		-2.37
		(1.57)		(1.57)		(1.57)		(1.57)
$(ln\ of)^2$		-0.56		-0.56		-0.59		-0.59
		(0.46)		(0.46)		(0.46)		(0.46)
$(ln\ of)^3$		-0.06		-0.06		-0.06		-0.06
		(0.06)		(0.06)		(0.06)		(0.06)
$(ln\ of)^4$		-0.00		-0.00		-0.00		-0.00
		(0.00)		(0.00)		(0.00)		(0.00)
Country FE	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Observations	506	506	506	506	506	506	506	506
Adjusted R^2	0.797	0.813	0.797	0.813	0.797	0.813	0.797	0.813

Notes: Endogenous variable is the ratio of OECD countries' imports of intermediate inputs from China over the countries' manufacturing value added. Constant and fixed effects not reported. Standard errors in parenthesis. ***Significant at 1 percent level, **Significant at 5 percent level, *Significant at 10 percent level.

Moving from column 1 to column 3 in table 2.1 and thereby doubling the assumed value for R doubles the estimated coefficient for α, while it has no impact on β. Introducing the additional control variables reduces the estimated coefficients. Moving from column 1 to column 5 and thereby increasing the value for σ from 3.8 to 5 drives up both estimated coefficients, for α and β. The coefficient for α is smaller than the estimated coefficient in column 3, but given that moving σ from 3.8 to 5 only implies an increase of roughly 30 per cent, the quantitative effect of changes in σ on α is stronger than the effect of changes in R. High values of σ and R in column 7 yield the highest estimates for α and β. In all estimated specifications, introducing the additional control variables reduces the estimated coefficients slightly.

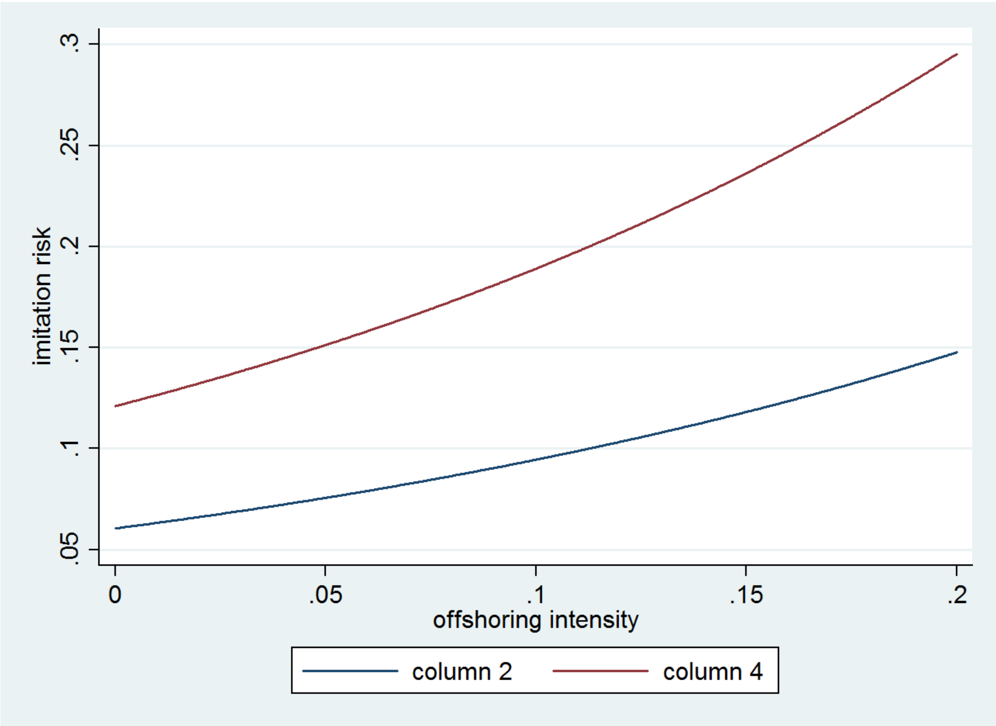

Figure 2.4: Perceived imitation risk.

Using the estimated parameters from table 2.1 I can back out the implied imitation risk. In figure 2.4 I show this perceived imitation risk for every level of offshoring intensity. Results are only reported for the estimates in column 2 and column 4 with $\sigma = 3.8$. The perceived imitation threat when using just a marginal share of intermediate inputs from China is at 6 per cent and 12 per cent, respectively. Increasing the importance of Chinese intermediate inputs to a level of 20 per cent of manufacturing value added, the implied imitation risk rises to 15 per cent and 30 per cent, respectively.

Moreover, I can calculate the gap in unit labor costs between developed countries and China that is justified by the imitation risk and report these results in figure 2.5. The reported number represents the level of long-run offshoring costs $\nu(i)$. I turns out that according to the estimates in column 2 of table 2.1 the imitation threat imposes an additional wage premium of 100 per cent that firms are willing to pay to domestic workers before they consider to start offshoring. This wage premium will be paid in addition to any wage premium justified by technological iceberg transport cost or communication costs. An offshoring intensity of 20 per cent will only be chosen if the domestic unit labor costs are roughly 300 per cent higher than unit labor costs in China. The higher imitation risk predicted in

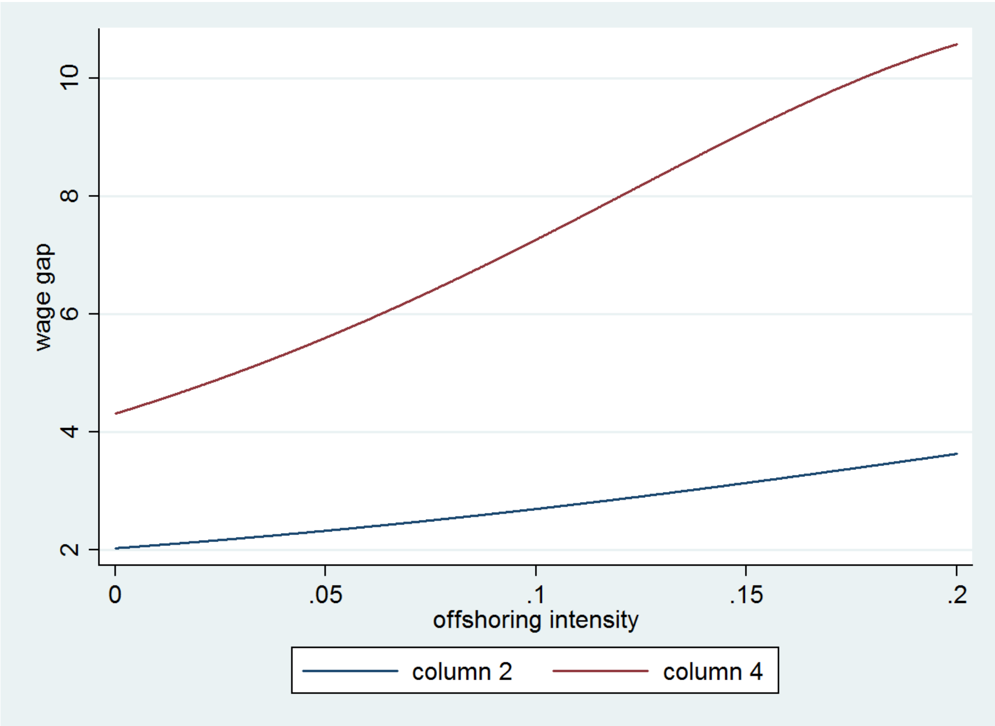

Figure 2.5: Justified wage gap w/w^*.

column 4 of table 2.1 justifies even higher wage gaps, ranging from a factor 4 when starting offshoring to a factor 10 when offshoring intensity reaches 20 per cent.

2.4 A dynamic product cycle model with offshoring

Having shown that the imitation risk is indeed crucial for firms' decision whether to use offshore production I now analyze the implications of imitation in a southern country in a dynamic product cycle model. Most important extension to the static model outlined above is the existence of a research sector in both countries which employs high-skilled workers.

2.4.1 Research sector

Conducted research in the North during an interval of time $\mathrm{d}t$ yields an expected number of successful innovations of $(N(t)/a)\,\mathrm{d}t$, where $1/a$ is generic research productivity and $N(t)$ is the stock of all consumed varieties at a certain point in time t. The appearance of $N(t)$ in this term is a spillover from present knowledge in line with Grossman and Helpman

(1991b), Aghion and Howitt (1992), or Romer (1990). It has the convenient feature to yield a constant growth rate of varieties $g(t) = \dot{N}(t)/N(t)$ when the absolute number of researchers remains constant.[10] With a sufficiently high number of high-skilled researchers, the aggregate uncertainty in the innovation process disappears, despite the presence of idiosyncratic uncertainty. This means that a new variety can be developed at a given cost

$$C(t) = \frac{s(t)a}{N(t)}, \tag{2.30}$$

where $s(t)$ is the salary of the high-skilled researcher. Due to the fact that all profits have to be distributed to high-skilled researchers the level of s is still the same as determined above in equation (2.4). High-skilled researchers in the South are not able to develop new varieties, but can only copy existing northern varieties. Consequently, every variety $n^*(t)$ produced in the South at any point in time has before already been produced in the North. However, I assume that the wage difference in the two countries is sufficiently large so that southern firms can set monopoly prices for their imitated varieties according to the elasticity of substitution, the so called "wide-gap case" from Grossman and Helpman (1991a). This case is formally characterized by the condition $w^*\sigma/(\sigma - 1) \leq w\Theta(I, w, w^*)$.[11] The expected number of successful copies during one time period is given by $\left(n(t)\int_0^{I(t)} \mu(i)\mathsf{d}i/a^*\right)\mathsf{d}t$, where $n(t)$ is the stock of northern varieties not yet imitated by southern firms, implying that imitation is more likely if the number of unrevealed northern varieties is high. Furthermore, $\int_0^{I(t)} \mu(i)\mathsf{d}i$ is the knowledge stock transferred from the North to the South via offshoring which increases the success probability of imitative research. Given the absence of aggregate uncertainty, this implies costs of

$$C^*(t) = \frac{s^*(t)a^*}{n(t)\int_0^{I(t)} \mu(i)\mathsf{d}i} \tag{2.31}$$

for a successful copy. Imitation is profitable because wages of production workers in the South are lower than those of northern production workers, $w(t) > \tau w^*(t)$, as mentioned above.[12] After a successful imitation southern firms can produce at lower cost than the northern incumbent firm and drive it out of the market. Consequently, profit-maximizing imitators

[10] Jones (1995) argues that spillovers have the form $N(t)^\phi$ with $0 < \phi < 1$. This "semi-endogenous growth theory" makes the growth rate depending on the population growth rate.

[11] In the "narrow-gap case" southern firms set prices slightly below northern firms' production costs to capture the entire demand for that variety. This limit price-setting can be interpreted as Bertrand price competition. Importantly, my results on the dynamic adjustment of offshoring and on income inequality do not depend qualitatively on the choice of price-setting.

[12] In the absence of differences in worker productivity this assumption requires that the South is abundantly endowed with production workers.

only target northern varieties but not southern varieties. The growth rate of total varieties is defined as $g(t) := \dot{N}(t)/N(t)$, which equals the growth rate of unrevealed northern varieties $\dot{n}(t)/n(t)$ and of southern varieties $\dot{n}^*(t)/n^*(t)$ on a balanced growth path. The imitation rate is $m(t) := \dot{n}^*(t)/n(t)$.

The research sector is characterized by a free entry condition in both countries. I refrain from analyzing the trivial case where research is not profitable and hence the growth rate of varieties is equal to zero. Instead, I assume that the no-arbitrage condition holds with equality. This implies that profits from successful innovation $\pi(t)$ and changes in the value of a northern firm exactly compensate for foregone interest payments and the risk of loosing the entire firm value due to imitation. Analogously, profits from successful imitation $\pi^*(t)$ and changes in the value of a southern firm exactly compensate only for interest payments foregone because the imitation risk is equal to zero. These relationships can be expressed as

$$\pi(t) + \dot{v}(t) = rv(t) + m(t)v(t) \qquad \text{and} \qquad \pi^*(t) + \dot{v}^*(t) = rv^*(t), \tag{2.32}$$

where $v(t)$ is the value of a northern firm and $v^*(t)$ is the value of a southern firm.

With southern production workers wages w^* as numéraire nominal firm values decrease with the rate of innovation $\dot{v}(t) = -g(t)v(t)$. The reason is that consumers spend their constant budget on an ever growing number of varieties. g can therefore be interpreted as the rate of depreciation of invested capital and the risk-free interest rate specified above in the static model can be written as $R = r + g$. Given that the value of a firm must equal the cost of research in equilibrium I obtain

$$\frac{s(t)a}{N(t)} = \frac{\pi(t)}{r + g(t) + m(t)} \qquad \text{and} \qquad \frac{s^*(t)a^*}{n(t)\int_0^{I(t)} \mu(i)\mathsf{d}i} = \frac{\pi^*(t)}{r + g(t)}. \tag{2.33}$$

Using equations (2.3) and (2.6) I can write output of each variety in the two economies as

$$x(t) = \frac{as(t)}{w(t)} \frac{r + g(t) + m(t)}{n(t) + n^*(t)} \frac{\sigma - 1}{\Theta(I, w, w^*, t)} \tag{2.34}$$

$$\text{and} \quad x^*(t) = \frac{a^*s^*(t)}{w^*(t)} \frac{r + g(t)}{n(t)} \frac{\sigma - 1}{\int_0^{I(t)} \mu(i)\mathsf{d}i}, \tag{2.35}$$

which allows me to solve for the relative profits of northern and southern firms

$$\frac{\pi(t)}{\pi^*(t)} = \frac{as(t)}{a^*s^*(t)} \frac{r+g(t)+m(t)}{r+g(t)} \frac{n(t)}{n(t)+n^*(t)} \int_0^{I(t)} \mu(i)\mathsf{d}i. \tag{2.36}$$

2.4.2 Labor markets

Full employment conditions for high-skilled workers are given by

$$hL = ag(t) \qquad \text{and} \qquad h^*L^* = \frac{a^*m(t)}{\int_0^{I(t)} \mu(i)\mathsf{d}i} \tag{2.37}$$

and serve to pin down the innovation rate in the steady state and the imitation rate, once the offshoring volume is determined.[13] Equation (2.37) reveals that the factor $\bar{\mu}$ which characterizes the imitation potential of the imitating country can now be written as $\bar{\mu} = h^*L^*/a^*$. Using equation (2.34) the full employment condition for northern low-skilled workers from equation (2.2) is given by

$$(1-h)L = a\frac{s(t)}{w(t)} \frac{n(t)}{n(t)+n^*(t)} \frac{1-I(t)}{\Theta(I(t))}(r+g(t)+m(t))(\sigma-1), \tag{2.38}$$

while using equation (2.35) the full employment condition for southern low-skilled workers from equation (2.5) can be written as

$$\begin{aligned}(1-h^*)L^* = {} & a\frac{s(t)}{w(t)} \frac{n(t)}{n(t)+n^*(t)} \frac{\tau I}{\Theta(I,w,w^*,t)}(r+g(t)+m(t))(\sigma-1) \\ & + a^*\frac{s^*(t)}{w^*(t)} \frac{n^*(t)}{n(t)} \frac{r+g(t)}{\int_0^{I(t)} \mu(i)\mathsf{d}i}(\sigma-1)\end{aligned} \tag{2.39}$$

where the first term on the right-hand side represents labor used for northern offshore production while the second term is labor in southern production.

[13]It can easily be seen that the innovation rate g only depends on exogenous parameters. This simplification makes the model analytically tractable and highlights the importance of imitation for the dynamic offshoring adjustment.

2.4.3 Intertemporal consumer optimization

The representative consumer in each country has an intertemporal utility function of the form

$$W = \int_0^\infty U(t)e^{-\rho t}\mathsf{d}t, \tag{2.40}$$

where ρ is the time preference factor. Maximization this function subject to the intertemporal budget constraint

$$\int_0^\infty e^{-rt}E(t)\mathsf{d}t \leq \int_0^\infty e^{-rt}w(t)\mathsf{d}t + A(0), \tag{2.41}$$

with $E(t)$ as consumer expenditure and $A(0)$ the value of assets in the initial period, yields the usual Euler equation for the growth rate of consumption expenditure

$$\frac{\dot{E}}{E} = r - \rho. \tag{2.42}$$

As is standard in the literature (see e.g. Grossman and Helpman, 1991b) the steady state is characterized by constant *nominal* wages so that *nominal* expenditure remains constant over time. This implies that the *nominal* interest rate always equal the discount factor of intertemporal utility. This normalization has no effect on real variables such as output or relative prices of the two economies.

2.4.4 Dynamic offshoring optimality

Inserting the two full employment conditions and the expression for long-run offshoring costs from equation (2.16) into equation (2.36) yields

$$\frac{\pi}{\pi^*} = \frac{(1-I)(1-h)L}{(1-I)(1-h^*)L^* - \tau I(1-h)L}\left(\frac{I}{1-I} + \nu(I)\right)\frac{n^*}{n}\tau, \tag{2.43}$$

which is an expression for relative profits that firms need to earn so that conducted research in both countries keeps the composition of varieties constant, depending on the level of offshoring. Moreover, inserting the expression for the offshoring savings factor $\Theta(I)$ from equation (2.19) into equation (2.9) I obtain

$$\frac{\pi}{\pi^*} = \Big(\tau I + \tau\nu(I)(1-I)\Big)^{1-\sigma}, \tag{2.44}$$

which is an expression for relative profits that firms will earn, depending on the offshoring volume. The offshoring equilibrium I must lie on the intersection of the two curves characterized by equations (2.43) and (2.44). Moreover, to ensure stability of the equilibrium, equation (2.44) must yield higher relative profits than equation (2.43) for all values $I' < I$. Under this condition, a small deviation from the equilibrium offshoring volume to a lower offshoring volume intensifies innovation in the North and slows down imitation in the South, so that the subsequent adjustment in the composition of varieties raises demand for northern production workers and drives up their wage, so that northern firms prefer a higher offshoring volume and the economy moves back to its equilibrium level of offshoring. In other words, the function of relative profits from the free entry condition in equation (2.43) must have a steeper slope than relative profits from production at the optimal offshoring level in equation (2.44). This pattern is shown graphically in figure 2.6.

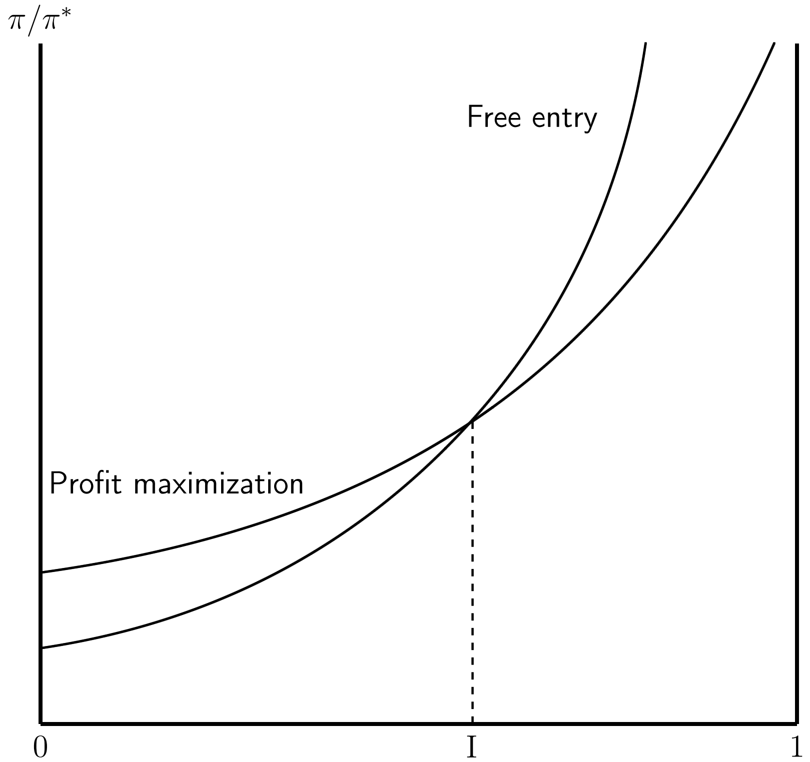

Figure 2.6: Relative profits in steady state.

Lemma 4 (Dynamic stability). The equilibrium is dynamically stable, given that the southern economy is not overly large in terms of endowment with production workers.

Proof. The elasticity of equation (2.44) with respect to I is given by

$$\begin{aligned}\frac{\widehat{\pi/\pi^*}}{\hat{I}} &= \frac{\mu(I)I}{r+g+m} - \frac{\Big(\mu'(I)(\sigma-1)(r+g+m) - \sigma\mu(I)^2\Big)(1-I)I}{(r+g+m)\Big((\sigma-1)(r+g+m)-(1-I)\mu(I)\Big)} \\ &< \frac{\mu(I)I}{r+g+m} \end{aligned} \tag{2.45}$$

where the inequality follows from the second order condition of static stability in equation (2.14). Moreover, the elasticity of equation (2.43) with respect to I is given by

$$\begin{aligned}\frac{\widehat{\pi/\pi^*}}{\hat{I}} &= \frac{L(1-h)\tau I}{L^*(1-h^*)(1-I)^2 - L(1-h)\tau I(1-I)} \\ &\quad + I\frac{\Big((\sigma-1)(r+g+m)-(1-I)\mu(I)\Big)^2 + (1-I)^2\Big((\sigma-1)(r+g+m)\mu'(I)-\sigma\mu(I)\Big)}{\Big((\sigma-1)(r+g+m)-(1-I)\mu(I)\Big)(\sigma-1)(r+g+m)(1-I)} \\ &> \frac{L(1-h)\tau I}{L^*(1-h^*)(1-I)^2 - L(1-h)\tau I(1-I)}\end{aligned} \tag{2.46}$$

where the inequality follows from the second order condition of static stability in equation (2.14) and the condition for positive offshoring costs in equation (2.17). Again using the condition for positive offshoring costs it can be shown that the term in equation (2.46) is strictly larger than the term in equation (2.45) whenever relative endowment with production workers is characterized by

$$\frac{L(1-h)}{L^*(1-h^*)} > \frac{(\sigma-1)(1-I)}{\tau(1+(\sigma-1)I)}, \tag{2.47}$$

so that the southern country cannot be too small relative to the northern country. □

2.5 Offshoring adjustment

All endogenous variables in the model react to changes in the endogenous offshoring volume. Hence, it is crucial to characterize the endogenous adjustment of the offshoring volume before analyzing the reaction of other endogenous variables. I denote with bold-face variables the ratio of a northern variable to the respective southern variable $\boldsymbol{z} := z/z^*$ and employ hat notation to refer to relative changes in variables so that $\hat{\boldsymbol{z}} := \hat{z} - \hat{z}^* := \mathsf{d}z/z - \mathsf{d}z^*/z^*$. The ratio of the two full employment conditions in equations (2.2) and (2.5) can, thus, be written as

$$\frac{1-I}{\boldsymbol{(1-h)L}} = \tau I + \frac{1}{\boldsymbol{nx}} \tag{2.48}$$

and the total differential of this expression is given by

$$(1-I)\frac{\widehat{\boldsymbol{(1-h)}} + \hat{\boldsymbol{L}}}{\boldsymbol{(1-h)L}} + \frac{I\hat{I}}{\boldsymbol{(1-h)L}} = \frac{\hat{\boldsymbol{n}} + \hat{\boldsymbol{x}}}{\boldsymbol{nx}} - \tau I\left(\hat{\tau} + \hat{I}\right), \tag{2.49}$$

which implies that changes in relative output of the two economies depends upon changes in their relative endowment with production workers, changes in the offshoring volume, and changes in offshoring costs which constitute iceberg transport cost for the southern economy.

Taking the total differential of the expresion for total offshoring costs in equation (2.15) yields

$$\hat{\boldsymbol{w}} - \hat{\tau} = \hat{\nu}(I), \tag{2.50}$$

where

$$\hat{\nu}(I) = \frac{\left(\mu'(I)(\sigma-1)(r+g+m) - \sigma\mu(I)^2\right)}{\left(I\mu(I) + (\sigma-1)(r+g+m)\right)\left((\sigma-1)(r+g+m) - (1-I)\mu(I)\right)}\mathsf{d}I > 0, \tag{2.51}$$

and the inequality was shown in lemma 2. Equation (2.8) yields

$$\hat{\boldsymbol{x}} = -\sigma\left(\hat{\boldsymbol{w}} + \hat{\Theta}(I)\right), \tag{2.52}$$

which allows me to write

$$\sigma\left(\hat{\tau} + \hat{\Psi}(I)\right) + \hat{\boldsymbol{x}} = 0, \tag{2.53}$$

where I define

$$\hat{\Psi}(I) := \hat{\nu}(I) + \hat{\Theta}(I) \tag{2.54}$$

as the intensive-margin effect of offshoring on relative labor demand, that means, labor demand embodied in tasks which remain performed in the North. It is negative if offshoring induces production costs of northern firms to fall relative to those of southern firms, so that output of each northern variety increases relative to output of each southern variety.

Lemma 5. The intensive-margin effect of offshoring on relative labor demand can be positive or negative, but has a well defined lower bound $\hat{\Psi}(I) > -\mathsf{d}I/(1-I)$.

Proof. The proof is in the Appendix. □

Equations (2.49) and (2.53) are sufficient to describe changes in the two economies for a constant ratio of varieties $\boldsymbol{n}$. The time during which this relative distribution of varieties remains fixed $\hat{\boldsymbol{n}} = 0$, even after disproportional changes in the innovation rate g or the imitation rate m, will be defined as the short run. The equilibrium which characterizes the economy during this time period is not a steady state, because northern and southern varieties do not grow at the same rate. Using this definition of a steady state and inserting $g := \dot{n}/n$ and $m := \dot{n}^*/n$ into $\dot{n}/n = \dot{n}^*/n^*$ yields $\boldsymbol{n} = g/m$ as the steady state composition of varieties. I define as the long run, the time which is needed until the composition of varieties has reached its new steady state level. Using equation (2.37) allows me to write

$$\hat{\boldsymbol{n}} = \hat{\boldsymbol{h}} + \hat{\boldsymbol{L}} - \frac{\mu(I)}{\int_0^{I(t)} \mu(i)\mathsf{d}i}\mathsf{d}I \tag{2.55}$$

which indicates the relative change in the ratio of product varieties moving to the new steady-state. Importantly, a stable offshoring equilibrium can only exist if demand for northern production labor relative to southern production labor $(1-h)L/(1-h^*)L^*$ is downward sloping in the offshoring volume I. Stability prevails because a small deviation from the equilibrium level of offshoring to a lower offshoring level creates excess demand for northern production labor, increasing the wage gap between northern and southern production workers and driving the offshoring volume back to the level where demand and supply of labor are in equilibrium. A similar reasoning applies for small upward deviations of the offshoring volume.

Lemma 6. Demand for northern production labor relative to southern production labor is downward sloping in the offshoring volume.

Proof. Inserting equation (2.53) into equation (2.49) while holding $\boldsymbol{\tau}$ and $\boldsymbol{n}$ constant yields

$$\left(\tau + \frac{1}{(\boldsymbol{1}-\boldsymbol{h})\boldsymbol{L}}\right)\mathsf{d}I + \frac{\sigma}{\boldsymbol{nx}}\hat{\Psi} = -(1-I)\frac{\widehat{(\boldsymbol{1}-\boldsymbol{h})} + \hat{\boldsymbol{L}}}{(\boldsymbol{1}-\boldsymbol{h})\boldsymbol{L}} \tag{2.56}$$

which implies that changes in relative demand for production labor must equal changes in relative production labor supply. For a relative labor demand schedule which is downward sloping in I the left-hand side must be positive. Using the fact that $\hat{\Psi}(I) > -\mathsf{d}I/(1-I)$ from lemma 5, substituting $1/\boldsymbol{nx}$ with the expression from equation (2.48), and using the condition on the relative endowment with production workers from lemma 4 yields

$$\frac{\widehat{L/L^*}}{\hat{I}} < 0 \tag{2.57}$$

□

Using these equations I can characterize relative changes in the offshoring volume induced by relative changes in technological offshoring costs. Intuitively, these changes show a negative correlation. A reduction of technological offshoring costs implies an increase in the offshoring volume. In the following lemma I focus on the difference between long-run and short-run adjustments.

Proposition 1. Given an exogenous reduction of offshoring costs τ, the increase in the offshoring level I is larger in the short run than in the long run.

Proof. Inserting equation (2.53) into equation (2.49) and holding $\boldsymbol{L}$, $\boldsymbol{h}$ and $\boldsymbol{n}$ constant yields relative changes in the short run as

$$\frac{\hat{I}^s}{\hat{\tau}} = -\frac{\tau I + \frac{\sigma}{\boldsymbol{nx}}}{I\left(\tau + \frac{1}{(\boldsymbol{1-h})\boldsymbol{L}}\right) + \frac{\sigma}{\boldsymbol{nx}}\frac{\hat{\Psi}}{\hat{I}}} < 0, \tag{2.58}$$

which is negative since the numerator is unambiguously positive, while the denominator is positive guaranteed by lemma 6. The relative change in the long run can be identified by additionally considering that changes in $\boldsymbol{n}$ are governed by equation (2.55) as

$$\frac{\hat{I}^l}{\hat{\tau}} = -\frac{\tau I + \frac{\sigma}{\boldsymbol{nx}}}{I\left(\tau + \frac{1}{(\boldsymbol{1-h})\boldsymbol{L}}\right) + \frac{\sigma}{\boldsymbol{nx}}\frac{\hat{\Psi}}{\hat{I}} + \frac{I\mu(I)}{\boldsymbol{nx}\int_0^{I(t)}\mu(i)\mathsf{d}i}} < 0, \tag{2.59}$$

which differs from the short-run effect in equation (2.58) only one additional term in the denominator. Since this term

$$\frac{I\mu(I)}{\boldsymbol{nx}\int_0^{I(t)}\mu(i)\mathsf{d}i} > 0 \tag{2.60}$$

it is easy to see that $\frac{\partial I^s}{\partial \tau} < \frac{\partial I^l}{\partial \tau} < 0$. □

This adjustment process is shown in figure 2.7, where the initial exogenous shift is an improvement in the offshoring technology, reducing τ to τ'. This drives down the relative wage of northern production workers to $(w/w^*)^s$ and the new offshoring volume is $I^s > I$

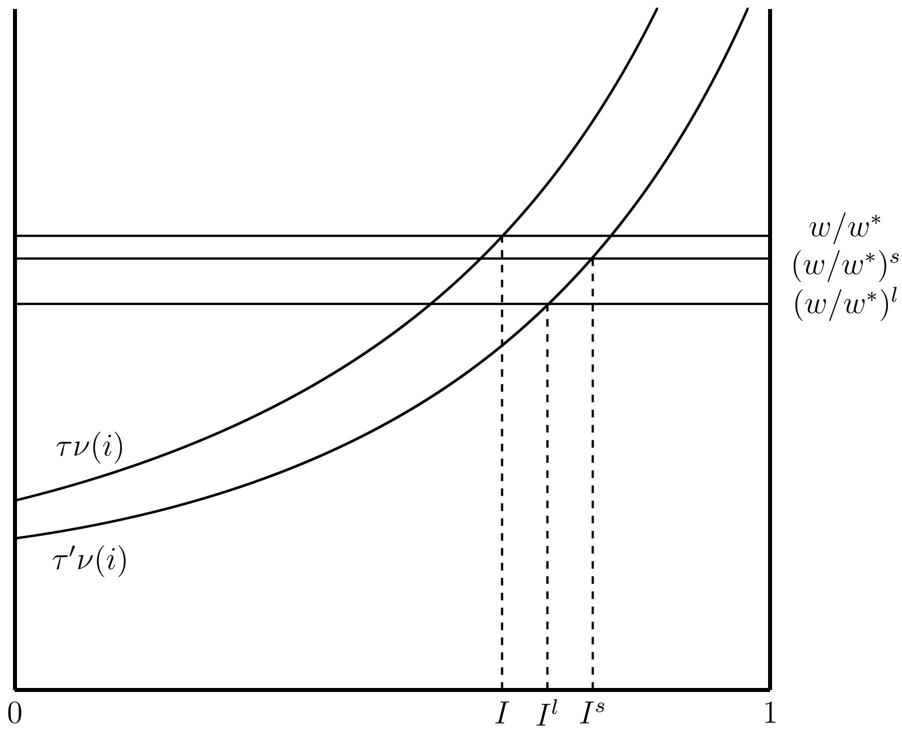

Figure 2.7: Offshoring adjustment

because potential savings on production costs become larger so that producers are willing to accept a higher imitation risk. The adjustment of the wage rate occurs immediately to eliminate any excess supply or demand for labor in any of the two countries.

The rising offshoring level induces an increase of the imitation rate from m to m^s and as outlined above the composition of varieties in the steady state is characterized by $n/n^* = g/m$. This means that the equilibrium characterized by $(w/w^*)^s$, I^s, m^s, and n/n^* cannot be a steady state because the composition of varieties has not yet adjusted. With this distribution, the number of imitated varieties $\dot{n}^*$ is too high and the net growth of northern varieties $\dot{n}$ is too small to maintain the composition of varieties constant. Hence, the subsequent time periods are characterized by a convergence of the relative composition of varieties to the new steady state $(n/n^*)^l = g/m^l$ with $g/m^s < g/m^l < g/m$, which will only be reached asymptotically. The slowly growing share of southern varieties drives up demand for southern production workers and therefore drives up their wage, so that each period is characterized by a slight decrease of the offshoring volume, which compensates for a part of the initial increase. In the new steady state when relative wages have slowly moved to $(w/w^*)^l$ the offshoring volume is I^l. The imitation rate is then m^l.

2.6 Wage inequality

Having analyzed how the offshoring level is affected by changes in exogenous variables, I now investigate how the skill premium reacts to changes in offshoring intensity. From equation (2.38) I can solve for the northern skill premium, ω, defined as

$$\omega := \frac{s}{w} = \frac{1-h}{h}\frac{\Theta(I)}{1-I} \cdot \frac{n+n^*}{n} \cdot \frac{g}{r+g+m} \cdot \frac{1}{\sigma-1} \tag{2.61}$$

which consists of four components: (1) efficiency units of low-skilled workers in domestic production relative to high-skilled workers; (2) the inverted share of northern varieties; (3) the growth rate of varieties relative to the discount rate of firm profits in the North; and (4) firm profits relative to production costs. The first three terms depend on various exogenous variables and the endogenous share of offshored tasks, while the fourth term depends only on the elasticity of substitution between varieties. Note that g depends on L and h, while m depends on L^*, h^*, and I. Moreover, the steady-state distribution of varieties is $(n+n^*)/n^* = (g+m)/m$.

To analyze changes in the skill premium with respect to changes in exogenous variables, I need to account for the relationships between offshoring volume and the respective exogenous variables derived above. However, how the skill premium changes with I is interesting in and off itself. The differentiated impact of offshoring on the skill premium via three effects is stressed in the seminal contribution by Grossman and Rossi-Hansberg (2008). This is a justifiable emphasis because it can be observed that the volume of trade in intermediate inputs rises much faster than gross output, which implies a rising share of offshore production, illustrated by a rising I. This rapid growth of offshoring is caused by improvements in the offshoring technology, such as information, communication, and transport, illustrated by a falling τ. In my model, as in most other relevant literature, technological offshoring costs have no direct effect on the skill premium in the North. Therefore, I can analyze exogenous changes in these costs simply by recognizing that a falling τ implies a rising level of offshoring, which in turn implies a rising productivity in northern production, characterized by a falling $\Theta(I)$.

Differentiating equation (2.61) with respect to I yields three components. The first and second correspond to the well-known productivity effect and labor supply effect, respectively.[14] Note that the productivity effect is negative since it works in favor of low-skilled workers, while the labor supply effect works in favor of high-skilled researchers and, hence, is positive. The analysis by Grossman and Rossi-Hansberg (2008) concerning the relative strength of the productivity effect and labor supply effect applies here as well. The first bit of offshoring does not increase productivity and, hence, works in favor of high-skilled researchers. However, the productivity effect may dominate the labor supply effect when the offshoring volume is large and the imitation risk function $\nu(i)$ rises steeply.

Moreover, there are two other effects that are innate to dynamic analysis and both are induced by an increase in the imitation rate. First, the intertemporal profit effect implies a reduction of the skill premium, due to a higher discount rate of future profit streams, which harms high-skilled researchers. Second, the composition effect is induced by the declining share of northern varieties which reduces demand for production labor and thus gives way to an increase of the skill premium. Again, I use a hat on a variable to refer to relative changes and thus write the above outlined relationship as

$$\hat{\omega} = \hat{\Theta}(I) + \frac{\mathrm{d}I}{1-I} + \chi \hat{m}(I), \tag{2.62}$$

where $\hat{\Theta}(I)$ and $\hat{m}(I)$ represent the elasticities of Θ and m with respect to I and

$$\chi := \frac{n^*}{n+n^*}\hat{n}^*(m) - \frac{m}{r+g+m} \tag{2.63}$$

where $\hat{n}^*(m)$ is the elasticity of n^* with respect to m.

Considering the timing of events more explicitly, it is important to remember that the short run is defined by a constant composition of varieties. This implies $\hat{n}^*(m) = 0$. Productivity effect, labor supply effect, and intertemporal profit effect do not rely on changes in the variety composition and set in instantaneously. The long-run, however, is defined by complete adjustment so that the variety composition has reached the new steady state. From equation (2.55) it is known that this implies $\hat{n}^*(m) = 1$ and the composition of varieties in the new steady state implies that the first term in equation (2.63) must be equal to $m/(g+m)$. The composition effect kicks in after the first period of higher imitation and increases further

[14] My analysis differs from Grossman and Rossi-Hansberg (2008) by having high-skilled researchers as fixed cost of production, a non-homothetic technology as coined by Horn (1983), whereas in Grossman and Rossi-Hansberg (2008) low-skilled and high-skilled labor are variable inputs into production of two types of goods. Hence, they do not focus on skill premia, but analyze changes in the wages of the high-skilled and low-skilled separately.

until the economy has reached a new steady state. The implications for the pattern of wage changes are summarized in the following proposition.

Proposition 2. Offshoring has a strictly positive short-run effect on the skill premium if and only if

$$\frac{\mathrm{d}I}{1-I} > \frac{m}{r+g+m}\hat{m}(I) - \hat{\Theta}(I), \tag{2.64}$$

and it has a strictly positive long-run effect on the skill premium if and only if

$$\frac{\mathrm{d}I}{1-I} + \frac{m}{g+m}\hat{m}(I) > \frac{m}{r+g+m}\hat{m}(I) - \hat{\Theta}(I). \tag{2.65}$$

Proof. Proposition 2 results from equations (2.62) and (2.63) under consideration that $\hat{n}^*(m) = 0$ in the short run and $\hat{n}^*(m) = 1$ in the long run. Moreover, $\frac{\mathrm{d}I}{1-I}$, $\frac{m}{r+g+m}\hat{m}(I)$, and $\frac{m}{g+m}\hat{m}(I)$ are all positive for $\mathrm{d}I > 0$ while $\hat{\Theta}(I)$ is negative for $\mathrm{d}I > 0$. Note that in equation (2.64) and equation (2.65) $\hat{m}(I) = \frac{\mu(I)}{\int_0^{I(t)} \mu(i)\mathrm{d}i}\mathrm{d}I$. □

These conditions imply that the wage premium will increase in the short run with the offshoring volume whenever the labor supply effect dominates productivity effect and intertemporal profit effect. Moreover, it will increase in the long run with the offshoring volume whenever labor supply effect and composition effect jointly dominate productivity effect and intertemporal profit effect. It is easy to see that equation (2.64) represents a stronger condition than equation (2.65). This implies that a positive short-run effect on the skill premium is a sufficient prerequisite for a positive long-run effect. Expressed differently, a positive long-run effect is a necessary implication of a positive short-run effect. When tracing these effects back to changes in technological offshoring costs it is important to remember that an exogenous reduction of τ leads to a strong increase of I in the short run, whereas I falls again in subsequent periods, compensating for part of the initial increase. However, this reaction of I with respect to changes in τ only affects the strength of the aggregate effect in the long run and in the short run. The sign of the long-run and short-run effect is entirely determined by the relative strength of the productivity effect, labor supply effect, intertemporal profit effect, and composition effect.

Nevertheless, it is crucial to note that different shocks of τ yield a different correlation of offshoring and relative wage movements. On the one hand, continued improvement of offshoring technology implies a constantly rising offshoring volume and an ambiguous reaction of the skill premium. The initial shock that drives up offshoring volume from zero to a positive value does not feature a productivity effect and is very likely to be to the favor of high-skilled researchers, giving a positively correlated movement of offshoring and the skill premium. Subsequent shocks to offshoring technology, however, may benefit low-skilled workers if the productivity effect becomes large.

On the other hand, after a nonrecurring shock to offshoring technology, offshoring volume rises in the short-run with an ambiguous reaction of the skill premium depending on the initial level of offshoring. If offshoring technology then remains constant in subsequent periods, the initial shock is followed by a reduction of the offshoring volume compensated for by rising imports of final goods and a rising skill premium in the dynamic adjustment toward a new steady state. This implies a negative correlation of offshoring and the skill premium.

2.7 Conclusion

In this paper I present a model of imitation risk and trade in tasks in the spirit of Grossman and Rossi-Hansberg (2008). In a static one-period model I derive a relationship between the wage gap between a developed and a developing country and the perceived imitation risk of firms. I structurally estimate this equation using data from Chinese exports of intermediate inputs to OECD countries. The imitation risk which justifies the observed pattern of changes in wages and changes in offshoring lies between 6 per cent and 12 per cent for a marginal importance of Chinese intermediate inputs in production, but is between 15 per cent and 30 per cent for countries that rely intensively on intermediate inputs from China.

Having shown the importance of imitation for firms' decision making, I present a dynamic product cycle model with offshoring and imitation and analyze its transitional dynamics. I find that the reaction of offshoring intensity to exogenous changes in technological offshoring costs is characterized by overshooting in the short run and subsequent convergence to a steady state when the composition of varieties endogenously adjusts.

Knowing the adjustment pattern of offshoring allows me to derive short-run and long-run comparative statics for the effects on wages of high-skilled researchers relative to those of low-skilled workers. In addition to the well-known productivity effect and labor supply effect, I identify a short-run intertemporal profit effect and a long-run composition effect. Given an increase in offshoring volume, the rising discount rate of future profit streams harms high-skilled researchers in the short run. In the long run, the endogenous adjustment of northern and southern varieties towards the new steady state more than compensates the high-skilled for the loss from a higher discount rate. However, these effects are not large enough to do away with the ambiguity of the aggregate wage effect derived by Grossman and Rossi-Hansberg (2008). An important implication is that the correlation of offshoring and relative wages depends not only on the initial level of offshoring as in Grossman and Rossi-Hansberg (2008), but also on the underlying shocks to offshoring technology.

Chapter 3

Task Trade and Intellectual Property Rights

3.1 Introduction

This paper studies the implications of intellectual property rights on the rate of innovation. In contrast to the existing literature it accounts for the fact that production of a final product may be sliced into small components or tasks, of which each is potentially manufactured at a different location. This phenomenon is most often referred to as *offshoring.*[1]

The paper has two key results. First, improving the level of intellectual property rights (IPR) protection does always lead to a reduction of the steady state growth rate. The reason is that a reduction in the probability of successful imitation has a detrimental effect on wages in the South. This harms the relative competitiveness of northern varieties and reduces incentives for innovation. Nevertheless, the effect on the importance of offshore production is ambiguous. This is because the implied reduction in the discount rate of firm profits makes the marginal increase in the imitation risk resulting from offshoring relatively more important in the firms' optimization problem. As a consequence, firms may reduce the level of offshoring even though instantaneous savings on production costs have been growing larger.

The second finding concerns the effect of a reduction in iceberg offshoring costs, which might either be result of technological progress or appropriate trade policy. It necessarily

[1] Empirical evidence on the magnitude and growth of offshoring can be found in Hummels et al. (2001), Yeats (2001), and Yi (2003).

drives up the share of offshore provided tasks because northern firms benefit from cost savings for all tasks already performed offshore and the resulting increase in the market share of northern varieties will partly be accommodated by increasing offshore production. However, the effect on the rate of innovation is ambiguous, because rising incentives for innovation might be dominated by a rise of imitation risk due to additional offshoring, which reduces innovation incentives.

Models of trade in tasks have been pioneered by Grossman and Rossi-Hansberg (2008, 2012). They account for the fact that value chains are split into more production stages than ever before and that a growing share of these stages is performed offshore in a potentially large number of countries. In those models, production of a final good requires a continuum of tasks to be performed and firms in the high-wage North may relocate a subset of these tasks to the low-wage South. The measure of tasks performed offshore is subject to the firms' optimization decision.

Based on previous work (Benz, 2013) I assume that offshoring of any additional task increases the risk of imitation for a northern variety. The intuition is that offshoring requires a high degree of interaction between northern firms and southern workers. This raises knowledge of southern workers about the final product and facilitates imitative research. Otherwise identical tasks can be ordered according to their information content about the final good, so that the marginal increase in the risk of imitation is an increasing function over the set of tasks. Moreover, offshore production comes at the cost of iceberg offshoring costs which are constant over the continuum of tasks. At the optimal offshoring level firms trade of cost savings with imitation risk to maximize the net present value of future profit flows.

The focus on imitation risk for firms' offshoring decisions can be justified by plenty of empirical evidence. In a survey conducted by Mansfield (1994) among 94 major US firms, the decision to conduct foreign direct investment (FDI) to manufacture components and to manufacture complete products was said to be strongly influenced by IPR legislation in 49 and 58 per cent of the cases, respectively.[2] Decisions to invest in facilities for research and development (R&D) were even affected by weak IPR in 80 per cent of the sampled companies. IPR protection was considered to be especially weak in India, where 44 percent

[2]A statistical significant negative correlation of this measure of IPR quality with the volume of US FDI is shown by Lee and Mansfield (1996). Very similar results were found in a survey among German and Japanese firms by Mansfield (1995).

of the firms would not start a joint venture with a local partner and 43 would not transfer their newest or most efficient technology even to wholly owned subsidiaries.[3] An empirical relationship of IPR protection with the international activity of multinational enterprises (MNEs) has also been identified by Branstetter et al. (2006, 2011), Canals and Sener (2011), and Naghavi et al. (2013).

FDI has a prominent role among the channels of international knowledge transmission. The Bureau of Economic Analysis (BEA) (2011) reports that in 2010 roughly two thirds of US royalty receipts were paid by US firms' foreign affiliates. Similarly high shares of within-company royalty flows have already been documented in the 1990s for the most important developed economies (UNCTAD, 1997). The importance of cross-border knowledge flows within multinational enterprises (MNEs) is also highlighted by Markusen (1995) who was the first to report that these companies are characterized by a high share of high-skilled workers and a high ratio of R&D to sales.

This model stands in the tradition of the product cycle literature which had started out as an idea by Vernon (1966). Grossman and Helpman (1991a) formalize the idea in a variety expansion model, where new patentable blueprints are developed in an R&D sector. These new varieties are only developed in the North and at some point in time can be imitated by southern producers, which shifts the location of production. They find that a lower rate of imitation reduces the innovation rate in the North. The reason is that northern wages rise due to the endogenous increase in the share of northern varieties, making innovation more costly and dominating the rising value of innovation from a reduced discount rate of firm profits.[4]

Helpman (1993) introduces FDI as second channel of international technology transfer. Northern varieties can be entirely produced in the South and then sold in the South or exported to the North. This does not change the outcome discussed above.[5] In Lai (1998) a lower rate of imitation facilitates the shift of production from northern firms to their southern affiliates, freeing northern resources to move into the research sector.

[3]Other countries that are considered risky targets of FDI were Nigeria, Brazil, and Thailand. Importantly, not only the written law is important but also the enforcement of the legislation.

[4]A similar result is identified in a quality ladder model by Segerstrom et al. (1990) who analyze the length of patent duration. In their model, prolonged protection lowers the rate of innovation because the cost of innovation rises with rising wages in the North, due to expanded labor demand from the production sector.

[5]The model is rather explicit about the timing of events. Intuitively, it takes time until changes in the rates of innovation and imitation will ultimately have a notable impact on the share of product varieties in the two countries. This may imply that a rising imitation rate may induce a temporary drop in the rate of innovation, before the wage effect outlined in Grossman and Helpman (1991a) is sufficiently strong.

Subsequently, a higher share of production is performed in the South, whereas the global rate of product development rises. Put differently, the effect from imitation on the present value of intertemporal profits dominates the effect on per-period profits through the wage rate.

Glass and Saggi (2001) show in a quality-ladder model that a reduction of offshoring costs can lead to an increase in the rate of innovation in the North, when it is accompanied by lower wages. Glass and Saggi (2002) were the first to account for the fact that imitation is endogenous and that labor has to be allocated to an imitative research sector in the South.[6] Equating cost of imitation with profits from imitation determines the allocation of labor to production and imitation in the South. In this setup tighter IPR protection increases the labor requirement in imitative research and the endogenous rate of imitation declines. Still it implies that more southern labor is allocated to research and the international production of MNEs is reduced endogenously. Glass (2004) introduces an imitation channel in the southern country that constitutes an increase in the cost of adapting a certain innovation to foreign sourcing.

In Branstetter et al. (2007), tighter IPR protection attracts more FDI to the South. In a similar model, Branstetter and Saggi (2009) conclude that IPR protection increases the rate of innovation in the North, when imitation is endogenous. Naghavi and Ottaviano (2009) emphasize difficulties in the communication between researchers and production workers in offshore production, which may lead to welfare losses if the offshoring decision fails to internalize the negative effect on research productivity.[7] Rodríguez-Clare (2010) explores the role of innovation on the welfare implications of offshoring. Assuming a fixed level of offshoring, he finds that dynamic gains from enhanced innovation can potentially compensate for static losses in the northern country. Acemoglu et al. (2012) study the long-run and short-run consequences of offshoring in a model with technical change. They find that offshoring and technical change are substitutes in the short run but complements in the long run. The impact of offshoring on skill inequality is largest at low levels of offshoring.

[6] Mansfield et al. (1981) show that the costs of imitation are roughly two thirds of the costs of innovation. Only very few products can be imitated at a cost of less than 20% of the innovation costs.

[7] Another mentionable paper is Lai et al. (2009), where offshoring is part of the innovative activity itself. Consequently, the contract that is written with an R&D subcontractor needs to take into account the leakage of knowledge to the South.

The remainder of this paper is organized as follows. Section 3.2 outlines the model, while section 3.3 characterizes the equilibrium. Section 3.4 derives the main results and section 3.5 concludes.

3.2 The model setup

This model stands in the tradition of the classical product cycle models with two countries, North and South. Both countries are inhabited by a fixed amount of consumers, each supplying one unit of labor inelastically, which may be used for either research or production. This means that in equilibrium wages for the two occupations must be equal. All variables that refer to the South are indicated by an asterisk (*).

3.2.1 Research sector

The number of produced varieties in the two countries is limited and the growth rate of varieties is endogenously determined. Research in the North can increase the total number of varieties. Each period of time, the success of individual research effort is a random function. However, with a high number of researchers there is no aggregate uncertainty in the innovation process, despite of the presence of idiosyncratic uncertainty. This means that a blueprint for a new variety can be developed at a cost

$$C = \frac{wa}{N}, \tag{3.1}$$

where N is the stock of all consumed varieties, which is identical to all varieties ever developed in the North. This formulation of the research cost involves spillover from present knowledge in line with Grossman and Helpman (1991a), Aghion and Howitt (1992), or Romer (1990).[8]

Innovation in the South is prohibitively costly but southern researchers are able to imitate existing southern varieties. Imitation is profitable, because lower wages in the South permit to drive the northern competitor out of the market. Again, imitation is subject to uncertainty, but a sufficiently high number of imitators means that a northern variety can

[8]Jones (1995) argues that spillovers have the form N^{ϕ} with $0 < \phi < 1$. This "semi-endogenous growth theory" makes the innovation rate exogenous, only depending on the population growth rate.

be imitated at costs of

$$C^* = \frac{w^* a^*}{\gamma n^* \int_0^I \mu(i) \mathsf{d}i}, \tag{3.2}$$

where $\gamma \in (0; 1]$ characterizes protection of intellectual property rights (IPR), n^* is the stock of southern varieties, indicating spillovers from imitation that already has occured in the past, and $\int_0^I \mu(i)\mathsf{d}i$ is the integral over a knowledge leakage function that depends positively on the offshoring intensity I and implies that a higher level of offshoring increases the success probability of imitative research, because offshoring means more knowledge spillovers from the North to the South. Imitation is less costly when γ is high, meaning a low level IPR protection. The limiting case with no IPR protection is normalized to $\gamma = 1$.

The growth rate of varieties is $g := \dot{N}/N$ and the imitation rate is $m := \dot{n}^*/n$. Entry into research is free in both countries. I abstain from analyzing the trivial case in which research is not profitable and the rate of innovation or the rate of imitation is equal to zero. Hence, the no arbitrage conditions must hold with equality in both countries, giving a relationship of per-period profits and the value of a northern firm as

$$\pi + \dot{v} = rv + mv \tag{3.3}$$

which implies that profits from successful innovation exactly compensate for interest payments forgone and the risk of losing the entire firm value v by being imitated. The southern no arbitrage condition is similar but does not contain an imitation risk term, because only northern firms are targeted by profit seeking imitators. Consequently, the southern no arbitrage condition is given by

$$\pi^* + \dot{v}^* = rv^*. \tag{3.4}$$

3.2.2 Manufacturing sector

Firms produce different varieties of an otherwise identical consumption good in a Dixit-Stiglitz setup. Production of one unit of final output requires the performance of a unit interval of tasks which can be performed offshore in a South at the cost of additional iceberg offshoring costs $\tau > 1$. Tasks differ with respect to the knowledge they reveal to the South when they are performed offshore.

By assumption, wages in the South are lower than in the North $w/w^* > 1$.[9] Northern firms chose the optimal level of offshoring to maximize the discounted value of future profits

$$\max_I \frac{\pi}{r+g+m} \tag{3.5}$$

and the first order condition of this maximization problem is given by

$$\frac{(\sigma-1)(w-\tau w^*)}{w(1-I)+w^*\tau I} = \frac{\gamma\mu(I)\bar{\mu}}{r+g+m} \tag{3.6}$$

where $\mu(I)$ is the marginal impact of offshoring on imitation through information leakage to the South and $\bar{\mu} = L_R^*/a^*$ represents imitation effort in the South by the number of southern researchers divided by the southern research labor requirement. Northern firms are small so that they assume this term to be fixed when making their individual decisions. The second order condition for optimality implies that all tasks $i \leq I$ are performed offshore in the South where I is determined by equation (3.6). It is then possible to solve for the relation wage of northern to southern workers as

$$\frac{w}{\tau w^*} = \frac{(\sigma-1)(r+g+m)+I\gamma\mu(I)\bar{\mu}}{(\sigma-1)(r+g+m)-(1-I)\gamma\mu(I)\bar{\mu}}, \tag{3.7}$$

and to define a factor of production cost savings from offshoring $\Theta(I) = Iw^*/w + (1-I)$ as

$$\Theta(I) = \frac{(\sigma-1)(r+g+m)}{(\sigma-1)(r+g+m)+I\gamma\mu(I)\bar{\mu}}. \tag{3.8}$$

with $\partial\Theta(i)/\partial I \leq 0 \,\forall i$. Production costs in the North are given by $w\Theta(I)$ and with Dixit-Stiglitz preferences producers charge a constant markup over production costs $p = w\Theta(I)\sigma/(\sigma-1)$. Thus, profits of each northern firm are given by

$$\pi = (p - w\Theta(I))x = \frac{w\Theta(I)x}{\sigma-1} \tag{3.9}$$

where one should bear in mind that x is still endogenous in this relationship, depending on w and I.

Southern firms do not use offshore production because wages of northern workers are higher than those of southern workers. Thus, their per-unit production costs are simply

[9]Since workers in both countries are indifferent between production and research, this assumption represents a condition on the relative productivity of innovation and imitation.

given by w^*. I assume that the wage difference between the two countries is sufficiently high so that southern firms can set monopoly prices according to the elasticity of substitution, the so called "wide-gap case" from Grossman and Helpman (1991a). This case is formally characterized by the condition $w^*\sigma/(\sigma-1) \leq w\Theta(I)$.[10] Thus, southern firms earn profits

$$\pi^* = (p - w^*)x^* = \frac{w^* x^*}{\sigma - 1}. \tag{3.10}$$

3.2.3 Consumer optimization

In this section I only display equations for northern consumers for the sake of brevity. However, analogous relationships hold for consumers in the South. Utility of the representative consumer in each period $U(t)$ is given by

$$U(t) = \left(\int_0^{N(t)} d_j(t)^{\frac{\sigma-1}{\sigma}} \mathsf{d}j \right)^{\frac{\sigma}{\sigma-1}}, \tag{3.11}$$

where $d_j(t)$ is consumption of variety j at time t and σ is the constant elasticity of substitution between varieties. Since trade in final products is costless it does not matter where these varieties are produced. Maximization yields a demand function

$$d_j(t) = \frac{E(t) p_j(t)^{-\sigma}}{\int_0^{N(t)} p_j(t)^{1-\sigma} \mathsf{d}j}, \tag{3.12}$$

where $p_j(t)$ is the price of variety j at time t and the term in the denominator is the well-known Dixit-Stiglitz price index. The intertemporal utility function with the form

$$W = \int_0^{\infty} e^{-\rho t} \log U(t) \mathsf{d}t, \tag{3.13}$$

is maximized subject to the intertemporal budget constraint

$$\int_0^{\infty} e^{-rt} E(t) \mathsf{d}t \leq \int_0^{\infty} e^{-rt} L w(t) \mathsf{d}t + n(0)v(0), \tag{3.14}$$

with $E(t)$ as expenditure for consumption and $n(0)v(0)$ is the initial value of asset holding. Intertemporal welfare maximization yields the usual Euler equation for consumption

[10]In the "narrow-gap case" southern firms set prices slightly below northern firms' production costs to capture the entire demand for that variety. This limit price-setting can also be interpreted as Bertrand price competition. Qualitative results are identical in the two pricing environments.

expenditure

$$\frac{\dot{E}}{E} = r - \rho. \tag{3.15}$$

so that the growth rate of expenditure is given by the interest rate r minus the discount factor ρ. Given the preference structure, relative demand for varieties only depends on relative prices so that

$$\frac{x}{x^*} = \left(\frac{p}{p^*}\right)^{-\sigma} = \left(\frac{w}{w^*}\Theta(I)\right)^{-\sigma} = \left[\frac{\tau(r+g+m)(\sigma-1)}{(r+g+m)(\sigma-1)-(1-I)\gamma\mu(I)\bar{\mu}}\right]^{-\sigma} \tag{3.16}$$

and relative profits can be written as

$$\frac{\pi}{\pi^*} = \left[\frac{\tau(r+g+m)(\sigma-1)}{(r+g+m)(\sigma-1)-(1-I)\gamma\mu(I)\bar{\mu}}\right]^{1-\sigma}. \tag{3.17}$$

3.2.4 Full employment

I assume that workers are free to move between the research sector and the production sector. Moreover, southern workers have the choice to work for domestic companies or can perform offshore production for northern firms. This means that wages for homogenous workers are equal in all occupations.

Northern workers only perform a fraction $1 - I$ of tasks domestically. Thus, the full employment condition satisfies

$$L = \frac{a\dot{N}}{N} + (1-I)nx, \tag{3.18}$$

while the full employment for southern workers is given by

$$L^* = \frac{a^*\dot{n}^*}{\gamma n^* \int_0^I \mu(i)\mathsf{d}i} + n^*x^* + \tau I n x \tag{3.19}$$

where the first term on the right-hand-side is labor used for imitative research, the second term is labor used for production of southern varieties, and the last term represents labor in northern offshore production.

3.3 Steady-state equilibrium

The following analysis is limited to a description of a steady-state equilibrium and will not capture the transition path from one steady-state to another. A steady-state equilibrium is defined by the condition that the number of varieties N, as well as n and n^*, grow at a constant rate g. The innovation rate g and the imitation rate m must be strictly positive. This implies that the share of northern varieties is given by $n/N = g/(g+m)$ and the ratio of southern to northern varieties is given by $n^*/n = m/g$.[11]

I use the southern wage rate w^* as numéraire and hold nominal aggregate output and nominal expenditure constant in the steady state. This implies that demand for each variety and the equilibrium value of each firm decreases at the rate g so that $\dot{v} = -gv$ and $\dot{v}^* = -gv^*$. Free entry implies that the value of a firm must equal the cost of research in equilibrium so that

$$\frac{wa}{N} = \frac{\pi}{r+g+m} \qquad \text{and} \qquad \frac{w^* a^*}{\gamma n^* \int_0^I \mu(i) \mathsf{d} i} = \frac{\pi^*}{r+g} \tag{3.20}$$

and relative profits are given by

$$\frac{\pi}{\pi^*} = \frac{r+g+m}{r+g} \frac{n^*}{N} \frac{w}{w^*} \frac{a\gamma \int_0^I \mu(i) \mathsf{d} i}{a^*}. \tag{3.21}$$

Inserting equation (3.7) into equation (3.21) and solving for relative research productivity of the two countries yields

$$\frac{a}{a^*} = \frac{\Big((r+g+m)(\sigma-1) - (1-I)\gamma\mu(I)\bar{\mu}\Big)^{\sigma} \Big((r+g+m)(\sigma-1)\Big)^{1-\sigma}}{\tau^{\sigma}\Big((r+g+m)(\sigma-1) + I\gamma\mu(I)\bar{\mu}\Big)\gamma \int_0^I \mu(i) \mathsf{d} i} \frac{r+g}{r+g+m} \frac{g+m}{m}, \tag{3.22}$$

which characterizes the equilibrium level of innovation and imitation that is consistent with profits earned in equilibrium. I will refer to this condition as the free entry condition and define the relative labor input coefficients into research as $A := a/a^*$. Combining equation

[11] By definition of the steady state $\dot{n}/n = \dot{n}^*/n^*$. Inserting the definitions of $g := \dot{n}/n$ and $m := \dot{n}^*/n$ yields $m = gn^*/n$ or $m/g = n^*/n$. Adding one and taking both sides to the power of minus one yields $g/(g+m) = n/(n+n^*)$.

(3.20) with equations (3.9) and (3.10) it is possible to solve for output of a northern firm as

$$\begin{aligned} x &= \frac{r+g+m}{n+n^*}\frac{a}{\Theta(I)}(\sigma-1) \\ &= \frac{a}{n+n^*}\Big((r+g+m)(\sigma-1)+I\gamma\mu(I)\bar{\mu}\Big) \end{aligned} \tag{3.23}$$

while output of a southern firm is given by

$$x^* = \frac{a^*}{\gamma n^* \int_0^I \mu(i)\mathsf{d}i}(r+g)(\sigma-1). \tag{3.24}$$

Using these expressions I can rewrite the full employment conditions so that from equation (3.18) I obtain

$$L = ag + (1-I)\frac{ag}{g+m}\Big((r+g+m)(\sigma-1)+I\gamma\mu(I)\bar{\mu}\Big). \tag{3.25}$$

while equation (3.19) yields

$$L^* = \frac{a^*\left(g\sigma + r(\sigma-1)\right)}{\gamma\int_0^I \mu(i)\mathsf{d}i} + \tau I\frac{ag}{g+m}\Big((r+g+m)(\sigma-1)+I\gamma\mu(I)\bar{\mu}\Big) \tag{3.26}$$

The offshoring volume I in the steady state is limited to $I \in [0;1]$. An equilibrium is implicitly defined by equations (3.22), (3.25), and (3.26) which jointly determine three endogenous variables g, m, and I. In the following I will define relationships that prove existence and uniqueness of this equilibrium.

3.3.1 Labor market equilibrium

Equation (3.25) can be solved for the imitation rate in equilibrium as

$$m = \frac{ag(1-I)\Big(r(\sigma-1)+I\gamma\mu(I)\bar{\mu}\Big)}{L-ag\Big(1+(1-I)(\sigma-1)\Big)} - g \tag{3.27}$$

which has a positive denominator because $r > 0$ and $\mu(I) > 0$, so that equation (3.25) yields $L > ag(1+(1-I)(\sigma-1))$. Moreover, the first term on the right-hand side is always strictly larger than g whenever $g > 0$.

Lemma 1. According to the northern full employment condition the imitation rate m increases with the innovation rate g so that $\partial m/\partial g > 0$ and it decreases with the offshoring volume I so that $\partial m/\partial I < 0$ given that $\mu(I) > I\mu'(I)$.

Proof. The partial derivative of m with respect to g is given by

$$\frac{\partial m}{\partial g} = \frac{m}{g} + \frac{a(g+m)\Big(1+(1-I)(\sigma-1)\Big)}{L-ag\Big(1+(1-I)(\sigma-1)\Big)} > 0 \tag{3.28}$$

which only has positive components so that the overall effect must be positive. The partial derivative of m with respect to I is given by

$$\frac{\partial m}{\partial I} = -\frac{ag\Big((r+g+m)(\sigma-1)-(1-2I)\gamma\mu(I)\bar{\mu}-(1-I)I\gamma\mu'(I)\bar{\mu}\Big)}{L-ag\Big(1+(1-I)(\sigma-1)\Big)} < 0 \tag{3.29}$$

which is is always negative when the information leakage function is not too convex, meaning that $\mu'(I)$ is not too large. This is proven by the fact that $(r+g+m)(\sigma-1)-(1-I)\mu(I) > 0$ so that the partial derivative is negative whenever $\mu(I) > (1-I)\mu'(I)$. □

According to the northern full employment condition, the imitation rate m decreases with the offshoring volume I and increases with the rate of innovation g. With constant rate of innovation g, an increase in the offshoring volume I reduces demand for northern labor. This must be counterbalanced by a reduction of m, increasing the share of northern varieties and, hence, demand for northern labor. With constant offshoring volume I, an increase in the rate of innovation g drives up the share of northern varieties and, hence, drives up demand for northern labor. This can only be counterbalanced by an increase of m which reduces the share of northern varieties and, hence, demand for northern labor. Consequently, for any given m the northern full employment condition is upward sloping in the I-g-space.

Corollary 1. The northern full employment condition is upward sloping in the I-g-space for any given imitation rate m.

Solving the southern full employment condition from equation (3.26) for the imitation rate yields

$$m = \frac{ag\tau\gamma I\int_0^I \mu(i)\mathsf{d}i\Big(r(\sigma-1)+I\gamma\mu(I)\bar{\mu}\Big)}{L^*\gamma\int_0^I \mu(i)\mathsf{d}i - a^*\Big(g\sigma+r(\sigma-1)\Big)-ag\tau\gamma(\sigma-1)I\int_0^I \mu(i)\mathsf{d}i} - g, \tag{3.30}$$

where the first term on the right-hand side has a positive denominator and is larger than g whenever $g > 0$.

Lemma 2. According to the southern full employment condition the imitation rate m increases with the innovation rate g so that $\partial m/\partial g > 0$ and it increases with the offshoring volume I so that $\partial m/\partial I > 0$.

Proof. The partial derivative of m with respect to g is given by

$$\frac{\partial m}{\partial g} = \frac{(g+m)^2 + m}{g} + \frac{a^*\sigma(g+m)}{ag\tau\gamma I \int_0^I \mu(i)\mathsf{d}i\Big(r(\sigma-1) + I\gamma\mu(I)\bar{\mu}\Big)} > 0 \tag{3.31}$$

which only has positive components so that the overall effect must be positive. The partial derivative of m with respect to I is given by

$$\frac{\partial m}{\partial I} = \frac{(g+m)\left(\int_0^I \mu(i)\mathsf{d}i\,(r(\sigma-1) + g + m + 2I\gamma\mu(I)\bar{\mu} + I^2\gamma\mu(I)'\bar{\mu}) - (\sigma-2)(g+m)I\gamma\mu(I)\bar{\mu}\right)}{I\gamma\int_0^I \mu(i)\mathsf{d}i\Big(r(\sigma-1) + I\mu(I)\Big)}$$
$$- \frac{a^*\Big(g\sigma + r(\sigma-1)\Big)(g+m)^2\gamma\mu(I)\bar{\mu}}{ag\tau I\left(\gamma\int_0^I \mu(i)\mathsf{d}i\right)^2\Big(r(\sigma-1) + I\gamma\mu(I)\bar{\mu}\Big)} > 0 \tag{3.32}$$

which is is positive when the marginal effect of offshoring on imitation is not too big so that $\mu(I)\bar{\mu}a^*\sigma < a\tau\left(\int_0^I \mu(i)\mathsf{d}i\right)^2$. □

According to the southern full employment condition, the imitation rate increases with the offshoring volume I and increases with the rate of innovation g. With constant rate of innovation g, an increase in the offshoring volume I increases demand for southern labor. This must be counterbalanced by an increase of m which has no effect on labor required to produce southern varieties but it reduces the share of northern varieties and, hence, reduces demand for southern labor working in offshore manufacturing of northern varieties. With constant offshoring volume I, an increase in the rate of innovation g drives down the share of northern varieties and, hence, reduces demand for northern labor. This can only be counterbalanced by an increase of m which reduces the share of northern varieties and, hence, demand for northern labor.

Corollary 2. The southern full employment condition is downward sloping in the I-g-space for any given imitation rate m.

Using equations (3.27) and (3.30) it is possible to write the innovation rate as a function of the offshoring volume. The resulting equilibrium characterized by I and

$$g = \frac{L^*\gamma(1-I)\int_0^I \mu(i)\mathsf{d}i - L\tau\gamma I\int_0^I \mu(i)\mathsf{d}i - a^*(\sigma-1)(1-I)r}{a^*\sigma(1-I) - a\tau\gamma I\int_0^I \mu(i)\mathsf{d}i}. \tag{3.33}$$

is a unique and stable equilibrium so that the two full employment conditions are satisfied. Uniqueness and stability of the equilibrium directly follows from the slope of the two curves, summarized in Corollary 1 and Corollary 2.

Lemma 3. Numerator and denominator of equation (3.33) are both positive.

Proof. It is possible to rewrite equation (3.33) as

$$g = \frac{L^*\gamma(1-I)\int_0^I \mu(i)\mathsf{d}i - L\tau\gamma I\int_0^I \mu(i)\mathsf{d}i - a^*(\sigma-1)(1-I)r}{\Psi a^*\sigma(1-I) - a\tau\gamma I\int_0^I \mu(i)\mathsf{d}i} \tag{3.34}$$

with $\Psi = 1$ and plug equation (3.34) into equation (3.27). Holding m constant and differentiating with respect to I and Ψ yields $\partial I/\partial\Psi < 0$. Since we know that for every constant m equation (3.27) implies $\partial I/\partial g > 0$ this shows that Ψ and g have opposite effects on I. Inspecting the denominator of equation (3.34) shows that this can only be true if $\Psi a^*\sigma(1-I) - a\tau\gamma I\int_0^I \mu(i)\mathsf{d}i$ and since we started from $\Psi = 1$ also $a^*\sigma(1-I) - a\tau\gamma I\int_0^I \mu(i)\mathsf{d}i$ so that an increase of Ψ increases the denominator of equation (3.34). Since the rate of innovation can only be positive this implies that the numerator of equation (3.34) must be positive as well. □

Proposition 1. The innovation rate g decreases with the offshoring volume in equation (3.33) so that $\partial g/\partial I < 0$. Consequently, the two full employment conditions characterize a downward sloping curve in the I-g-space.

Proof. The partial derivative of g with respect to I is given by

$$\begin{aligned}\frac{\partial g}{\partial I} = & \frac{L^*\gamma\left(a\tau\gamma\left(\int_0^I \mu(i)\mathsf{d}i\right)^2 + a^*\sigma(1-I)^2\mu(I)\right)}{\left(a^*\sigma(1-I) - a\tau\gamma I\int_0^I \mu(i)\mathsf{d}i\right)^2} \\ & - \frac{a^*\tau\left(L\sigma + a(\sigma-1)\gamma r\right)\left(\int_0^I \mu(i)\mathsf{d}i + I(1-I)\mu(I)\right)}{\left(a^*\sigma(1-I) - a\tau\gamma I\int_0^I \mu(i)\mathsf{d}i\right)^2} < 0\end{aligned} \tag{3.35}$$

which is negative whenever the offshoring volume is at least slightly larger than zero or $L\tau I > L^*(1-I)^2\mu(I)$ and $LI > ga$, which means that the share of offshoring in northern production is larger than the share of researchers in northern employment. □

3.3.2 Free entry

Remember that the free entry condition in equation (3.22) is given by

$$A = \frac{\Big((r+g+m)(\sigma-1)-(1-I)\gamma\mu(I)\bar{\mu}\Big)^{\sigma}\Big((r+g+m)(\sigma-1)\Big)^{1-\sigma}}{\tau^{\sigma}\Big((r+g+m)(\sigma-1)+I\gamma\mu(I)\bar{\mu}\Big)\gamma\int_0^I \mu(i)\mathsf{d}i}\frac{r+g}{r+g+m}\frac{g+m}{m}, \tag{3.36}$$

and characterizes the equilibrium level of innovation and imitation that is consistent with profits earned in equilibrium.

Lemma 4. An increase in the imitation rate and an increase in the innovation rate boost incentives to enter the market in the North relative to the South, while an increase in the offshoring volume has the opposite effect so that $\partial A/\partial m > 0$, $\partial A/\partial g > 0$, and $\partial A/\partial I < 0$.

Proof. The proof is in the appendix. □

The intuition for the first effect is that an increase in the imitation rate reduces the *relative* importance of offshoring as additional driver of imitation. Consequently, a given level of offshoring will already be chosen at a smaller wage gap between North and South. This reduces the relative price of northern to southern varieties and drives up demand for northern products. However, if the offshoring volume is too high most of the additional demand for northern output will be produced by southern offshore workers. In such a situation the resulting equilibrium may not be stable. Since single countries are usually only small contributors of intermediate inputs to other countries' gross output it is plausible to assume I to be sufficiently small so that this relationship holds.

An increase in the innovation rate has an identical effect on the wage gap between North and South as an increase in the imitation rate. Moreover, it shifts the composition of varieties so that in the new steady state northern researchers benefit from relatively more spillovers than southern researchers. Via both of these channels an increase in the innovation rate makes entry in the North relatively more attractive.

Offshoring compensates northern firms for the imitation risk with savings on production costs. Consequently, by increasing the level of offshoring northern firms can reduce their cost of production and increase demand for their output, which makes entry in the North more attractive. However, this effect is dominated by the effect of offshoring on the imitation probability, which makes imitation more profitable and consequently has an incentivizing effect on entry in the South.

Proposition 2. The free entry condition characterizes an upward sloping curve in the I-g-space.

Proof. The slope of the free entry condition in the I-g-space is given by

$$\frac{\mathsf{d}g}{\mathsf{d}I} = -\frac{A_I}{A_g} = -\frac{\frac{\partial A}{\partial I} + \frac{\partial A}{\partial m}\frac{\partial m}{\partial I}}{\frac{\partial A}{\partial g} + \frac{\partial A}{\partial m}\frac{\partial m}{\partial g}} \tag{3.37}$$

where the numerator is negative because $\partial A/\partial I < 0$ and $\partial A/\partial m > 0$ have been shown in lemma 4 while $\partial m/\partial I < 0$ has been shown in lemma 1 using the northern full employment condition, whereas $\partial A/\partial g > 0$ and $\partial A/\partial m > 0$ have been shown in lemma 4 while $\partial m/\partial I > 0$ has been shown in lemma 2 using the southern full employment condition. □

3.4 The effect of IPR protection and offshoring costs

In this section I analyze the effects of two different policy changes. The first considered policy change is a reduction of iceberg offshoring costs τ to facilitate offshore production of northern firms and reduce the implied welfare losses from costly transport. The second policy change is an improvement of intellectual property rights, meaning a reduction of the spillover factor γ. I will show that these two policy changes have different effects on the offshoring volume and the rate of innovation.

Proposition 3. A reduction of offshoring costs unambiguously increases the offshoring volume but has an ambiguous effect on the innovation rate.

Proof. The partial derivative of equation (3.33) with respect to τ is given by

$$\frac{\partial g}{\partial \tau} = -\frac{(L - ag)\gamma I \int_0^I \mu(i)\mathsf{d}i}{a^*\sigma(1 - I) - a\tau\gamma I \int_0^I \mu(i)\mathsf{d}i} < 0, \tag{3.38}$$

which implies that a reduction of iceberg offshoring costs τ shifts the full employment curve in the I-g-space up. Moreover, the partial derivative of equation (3.16) with respect to τ is given by

$$\frac{\partial A}{\partial \tau} = -\frac{\sigma A}{\tau} < 0 \tag{3.39}$$

which implies that a reduction of iceberg offshoring costs τ shifts the free entry curve in the I-g-space down. The resulting new equilibrium must be characterized by a higher offshoring volume. □

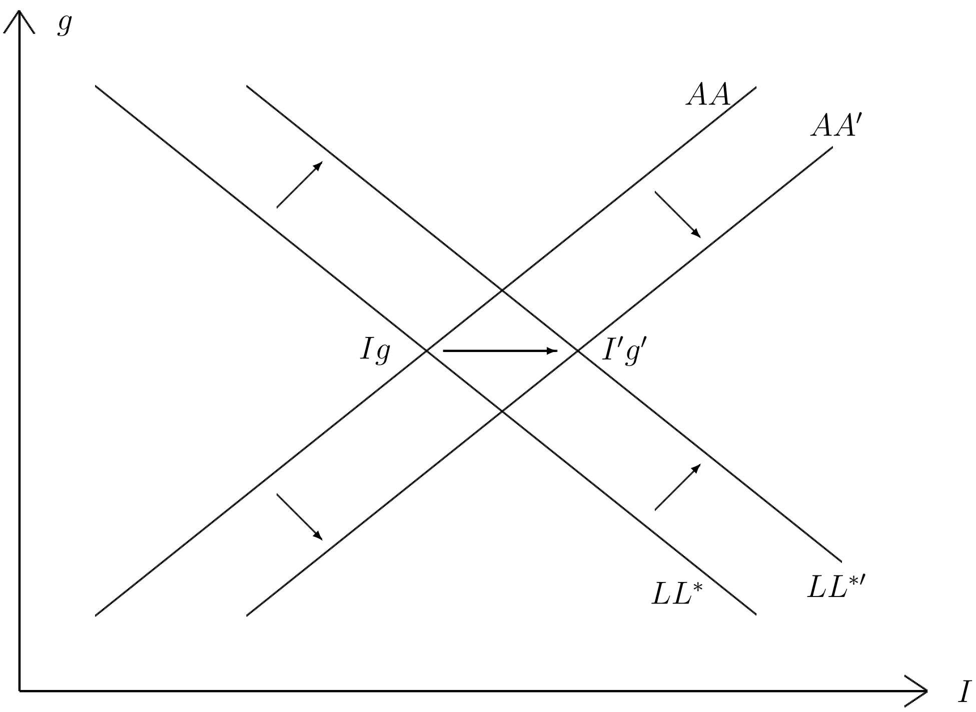

Figure 3.1: Reduction of iceberg offshoring costs.

The result from the previous proposition can easily be seen in figure 3.1. The following intuition explains this pattern. A reduction of τ relaxes the southern full employment condition. This can be counterbalanced via three channels. (1) An increase in I which requires more southern labor in offshore production because the South produces a larger share of each northern variety; (2) An increase in g which requires more southern labor in imitative research; (3) An increase in $g/(g+m)$ which requires more southern labor in offshore production because northern varieties have a relatively higher market share. In equilibrium both adjustment channels will accompensate part of the total effect so that the full employment curve is shifted upwards to a higher g and to the right to a higher I.

Moreover, a reduction of τ makes market entry in the North relatively more attractive, because it reduces the cost of production for northern firms. Countervailing forces which make entry in the North relatively less productive are a reduction of g or an increase of I. A lower rate of innovation reduces spillovers for northern researchers and increases the wage gap between North and South for a given offshoring volume, so that southern firms experience a bigger cost advantage for their final product. A higher offshoring volume reduces the cost of imitation and facilitates entry in the South.

At the new intersection of the full employment curve and the free entry curve, the offshoring volume must be unambiguously higher than in the old equilibrium. The change of the innovation rate is ambiguous and depends on model parameters.

Proposition 4. An improvement of IPR protection unambiguously decreases the innovation rate and the imitation rate but has an ambiguous effect on the offshoring volume.

Proof. The partial derivative of equation (3.33) with respect to γ is given by

$$\frac{\partial g}{\partial \gamma} = \frac{\Big(L^*(1-I) - (L-ag)\tau I\Big)\int_0^I \mu(i)\mathsf{d}i}{a^*\sigma(1-I) - a\tau\gamma I\int_0^I \mu(i)\mathsf{d}i} > 0, \tag{3.40}$$

which has a positive numerator because the numerator of equation (3.33) is positive and implies that an improvement of IPR protection (reduction of γ) shifts the full employment curve in the I-g-space down. Moreover, the partial derivative of equation (3.16) with respect to γ is given by

$$\frac{\partial A}{\partial \gamma} = -\frac{\sigma(1-I)\mu(I)\bar{\mu}A}{(r+g+m)(\sigma-1)-(1-I)\gamma\mu(I)\bar{\mu}} - \frac{I\mu(I)\bar{\mu}A}{(r+g+m)(\sigma-1)+I\gamma\mu(I)\bar{\mu}} - \frac{A}{\gamma} < 0 \tag{3.41}$$

which implies that an improvement of IPR protection (reduction of γ) also shifts the free entry curve in the I-g-space down. Thus, the new equilibrium must be characterized by a lower rate of innovation. Changes of the imitation rate are determined by I and g in equations (3.27) and (3.30). Since $\partial m/\partial g > 0$ in both equations while the partial derivetives of m with respect to I have opposite signs in the two equations, m must unambiguously decrease with a decreasing g. □

It is easy to see in figure 3.2 that the new equilibrium after an improvement of IPR protection features a lower innovation rate g while the effect on the offshoring volume is ambiguous. In the following I will describe the intuition for the result from proposition 4.

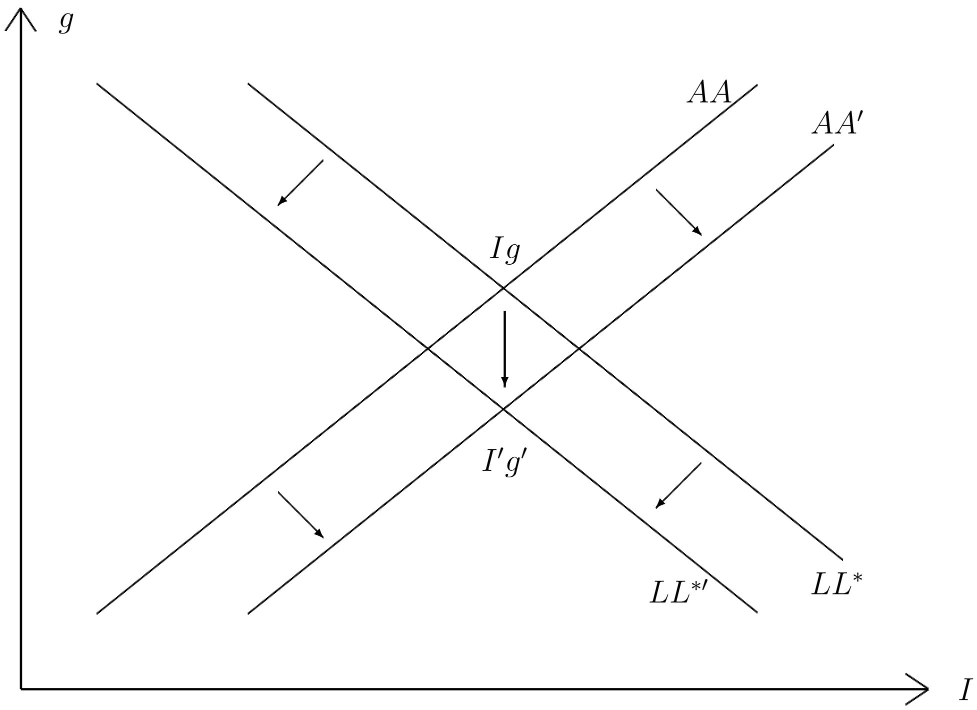

Figure 3.2: Improvement of IPR protection.

Stronger intellectual property rights mean that more southern labor is required for successful imitation. This can either be counterbalanced by a reduction of I, a reduction of g, or a reduction of $g/(g+m)$. In any case, the full employment curve is shifted downwards. Moreover, stronger IPR protection disincentivizes imitation and makes entry in the South relatively less attractive. Two channels can maintain the free entry condition in equilibrium. Either the offshoring volume must be raised, which increases spillovers from North to South and makes entry in the South more attractive. Or the innovation rate must go down, which reduces spillovers from existing research in the North and makes entry there relatively less attractive. Consequently, the free entry curve must be shifted downwards.

3.5 Conclusion

In this paper I analyze the role of intellectual property rights and offshoring costs on the rate of innovation in a product cycle model, where production can be sliced into tasks that are potentially performed offshore. Offshoring reduces production costs and increases instantaneous profits, but comes at the cost of information leakage that increases the imitation risk.

Because imitation implies a certain probability of losing future profits, optimizing firms trade off these two forces against each other when deciding about the optimal offshoring volume.

I show that an improvement of intellectual property rights in the South has a detrimental effect on the rate of innovation in the steady state. The intuitive explanation is that better IPR protection widens the wage gap between North and South and reduces the market share of each northern variety. Lower profits but higher wages imply that innovation can only remain profitable if firm values rise. The adjustment must come via a reduction of g, which is one of the elements in the discount factor of firm profits. Moreover, it implies a reduction of the imitation risk m.

Offshoring in the model is subject to iceberg offshoring costs. It can be shown that a reduction of these costs unambiguously increases the offshoring volume because cost savings from offshoring become larger, so that optimizing firms are willing to accept a higher marginal risk of imitation relative to their profit discount factor. However, the effect of offshoring costs on the absolute level of imitation cannot be unambiguously determined. Neither can be determined the effect on the innovation rate.

Chapter 4

Trade in Ideas: Outsourcing and Knowledge Spillovers*

4.1 Introduction

Productive knowledge and innovation are major determinants of economic prosperity. This hypothesis was theoretically formulated in the "new" growth theory, see e.g. Barro and Sala-i-Martin (2004). In these models growth is often fostered by knowledge spillovers, which lead to a widespread acceptance of subsidies to support research activity. For these subsidies to operate efficiently they should be directed towards an appropriate spillover channel. However, until now it is not completely understood which carriers of spillovers are important. We contribute to this literature by analyzing a largely neglected channel, spillovers through outsourcing relationships.

The concept of linkages between firms and industries as determinants of productivity spillovers goes back to the seminal work by Balassa (1961). Brown and Conrad (1967) used the input-output table to measure the "closeness" of industries, while knowledge spillovers due to the exchange of goods have been identified by Griliches (1979). In recent years the static optimization of a firm's sourcing decision has been analyzed for the closed economy by Grossman and Helpman (2002) and for the open economy and heterogeneous firms by Antràs and Helpman (2004).

*This chapter is joint work with Mario Larch and Markus Zimmer.

In the tradition of the literature estimating the "knowledge production function" (KPF) we formulate a model in which the outsourcing of intermediate goods production to other firms is a source of knowledge spillovers. These spillovers depend on the knowledge stock already acquired in an industry and occur between and within industries. Our estimation procedure is in line with the literature on the KPF that originated from Griliches (1979) and Griliches and Pakes (1984) which focuses on regional spillovers rather than on domestic spillovers through the intermediate products channel. To simplify the analysis we assume the outsourcing pattern to be exogenously given in a way that matches the actually observed input-output data. Given this idea we perform an empirical test of our hypothesis that firms are more innovative if they engage more in the exchange of intermediate inputs with other innovative firms.[1]

The modeling of spillovers due to usage of intermediate goods is also used by Badinger and Egger (2008) who estimate intra- and inter-industry spillovers with industry-level data of 15 manufacturing sectors and 13 OECD countries. They find evidence that intra-industry spillovers are usually larger than inter-industry effects. Javorcik (2004) uses a different approach without using spatial econometrics. She finds evidence of backward spillovers from international firms located in Lithuania to their upstream contractors.

We find forward spillovers to be strong: A one unit increase in the patent stock of all firms that deliver intermediate inputs to a specific firm raises annual patent output of this firm by 0.43 percent. Of these forward spillovers, those between industries are substantially more important than intra-industry spillovers. For backward spillovers we only estimate a semi-elasticity of 0.15, which does not differ significantly between inter-industry and intra-industry spillovers.

The remainder of the paper is organized as follows. In section 4.2, we motivate our hypothesis of the beneficial effect of outsourcing-driven knowledge spillovers. Section 4.3 describes the data that we use, while section 4.4 explains the estimation technique. Section 4.5 presents and discusses our obtained results and section 4.6 concludes.

[1] The traditional hypothesis in the KPF literature would state that firms are more innovative if they are in or close to a region with many other innovative firms or institutions.

4.2 Knowledge capital and sector linkages

The theoretical foundation for our empirical analysis comes from the well-established literature of endogenous technological change and from the knowledge production function (KPF) literature. In these models R&D efforts typically expand the variety of inputs, which allows for an increase in the division of labor, thus raising productivity. This type of process innovation is based on the idea of Young (1928) and was first established by Romer (1987, 1990), or in an alternative interpretation as product innovation by Grossman and Helpman (1991b,c).[2] Coe and Helpman (1995) integrated the concept of the KPF in a product variety endogenous growth model framework.

In this model, the number of newly developed blueprints $\dot{n}_i$ is a function of labor input L_i^R, input coefficient a, and some stock of knowledge capital K_i:

$$\dot{n}_i = \frac{L_i^R K_i}{a}. \tag{4.1}$$

A similar equation is estimated, amongst others, by Eaton and Kortum (1996). In this model, a high level of imports from an innovative economy has a positive effect on domestic patenting activity. A collection of further popular papers estimating the KPF is listed in table 4.1. This compilation is far from complete, but should give a representative picture of how diverse the approaches are in the specification of the economic model, the resulting estimation equations, the choice of the estimation method and the considered types of spillovers.

[2]Good representations of these so called product variety endogenous growth models can be found in Aghion and Howitt (2009, Ch. 3) or in Acemoglu (2009, Ch. 15).

Article, data type, and base model	Estimation method, spillover type, and base equation for estimation of knowledge production function
Jaffe (1989), panel data, modified Cobb-Douglas model	3-equation simultaneous system and some IV-specifications, regional spillovers from universities to enterprises $$ln(P) = b_1ln(RD) + b_2ln(U) + b_3[ln(U)ln(C)] + e$$
Acs et al. (1992), panel data, modified Cobb-Douglas model	OLS, regional spillovers from universities to enterprises $$ln(I) = b_1ln(RD) + b_2ln(U) + b_3[ln(U)ln(C)] + b_4ln(L) + e$$
Eaton and Kortum (1996), cross-section, equations are motivated from a Grossman and Helpman (1991b) type endogenous growth model	Simultaneous estimation of the patent equation, the growth equation and the relative productivity level equation by two-step feasible generalized non-linear least squares, spillovers from one country to another influenced by geographical distance, level of human capital in adopting country and imports relative to GNP $$ln\left(\frac{P}{L}\right) = b_0 + ln(d) + b_1ln\left(\frac{R}{L}\right) - ln\left(\frac{c}{Y}\right) + ln\left(\frac{y_i}{y_n}\right) + e$$
Acs et al. (2002), cross-section, modified Cobb-Douglas model	OLS, regional spillovers from local R&D staff and from local university research expenditures to innovative activity $$ln(I) = b_1ln(RD) + b_2ln(U) + b_3ln(Z) + e$$
Bottazzi and Peri (2003), panel data, Romer (1990) type endogenous growth model	OLS and IV, regional distance weighted R&D spillovers $$ln(I) = b_0 + b_1ln(w_1RD) + b_2ln(w_2RD) + \ldots + b_Nln(w_NRD) + b_{N+1}ln(RD) + e$$
Moreno et al. (2005), panel data, modified Cobb-Douglas model	Spatial econometrics, regional spillovers from innovation in other regions to innovation in the observed region as well as regional spillovers from R&D investments $$ln(I) = b_1ln(RD) + b_2ln(Y) + b_3ln(MA) + b_4Wln(I_i) + \sum_i(b_iNA_i) + e$$

Article, data type, and base model	Estimation method, spillover type, and base equation for estimation of knowledge production function
Zucker et al. (2007), panel data, model not motivated	Random effects Poisson, regional spillovers from universities, firms, government and other patent stocks to new patents $$ln(P) = b_0 + b_1 KS + b_2 PS + b_3 RD + e$$
Gumbau-Albert and Maudos (2009), panel data, modified Cobb-Douglas model	Negative Binomial, regional R&D and human capital spillovers weighted by distance and trade flows $$ln(P) = b_1 ln(RD) + b_2 ln(H) + b_3 ln(wRD) + b_4 ln(wH) + e$$
de Rassenfosse and van Pottelsberghe de la Potterie (2009), cross-section, ”inspired by” Romer (1990) type endogenous growth models	Robust OLS, no spillovers $$ln(P) = ln(w) + \sum_n (w_n ln(X_n)) + s ln(R) + \sum_m (s_m ln(X_m)) + e$$

Table 4.1: Summary of previous research and estimation strategies

Abbreviations: e: error term, P: patents, RD: R&D expenditures, U: university research, C: geographic distance to university, L: population or workforce, I: innovations, R: researchers, c: patenting costs, Y: output or GDP, y_i/y_n: relative productivity level of i, d: determinants of technology diffusion, Z: local level of concentration of e.g. innovation networks or knowledge, $w_1 RD$: weighted R&D within distance category 1 (e.g. 0-300km), $w_2 RD$: weighted R&D within distance category 2 (e.g. 300-600km), $w_N RD$: weighted R&D within Nth distance category, MA: quota of manufacturing employment, NA: national dummies, W: spatial weight matrix, KS: knowledge stock, PS: patent stock, H: regional human capital, wRD: weighted regional R&D spillovers, wH: weighted regional human capital spillovers, w: propensity to patent, w_n: n specific part of propensity to patent, X: various explanatory factors, s: productivity of researchers, s_m: m-specific part of productivity of researchers

The theoretical structure of our paper is most closely related to Eaton and Kortum (1996). However, their study analyzes spillovers due to trade between countries, while our paper focuses on spillovers between firms. This focus on firm as observational unit allows us to analyze an important source of firm-level spillovers: trade with intermediate inputs between firms within a country. Even though spillovers along the lines of international trade flows have received high attention in the past, no other study has so far tried to identify intra-country trade flows as source of knowledge spillovers. This seems surprising in light of the high potential for such spillovers. Even though we observe high and increasing volumes of international trade which are potential knowledge transmitters, trade flows within an economy are quantitatively still more important than international trade flows in almost all countries. And given that the technological advantage of R&D-intensive and highly productive firms over less productive firms is potentially large, these flows of intermediate inputs constitute an important channel for knowledge transfers.

We provide this missing link in the literature by estimating a knowledge production function with a focus on spillovers through trade of intermediate inputs. Importantly, our data on firm-specific patent activity is key for this type of analysis. A relationship where the stock of patent blueprints in each firm has a positive impact on innovative activity of one firm can be formulated as:

$$K_i = \sum_{j=1}^{I} w_{ij} n_j, \tag{4.2}$$

where n_j is the stock of blueprints of firm j and w_{ij} is the weight that is attributed to firm j in generating knowledge for firm i, as determined by the level of intermediate goods trade between the two firms. Intuitively, all $w_{ij} \, \forall \, j \neq i$ are smaller than w_{ii}.

The hypothesis that trade in intermediate inputs between firms contributes to an increase in a firm's knowledge stock is further motivated by the fact that outsourcing of intermediate inputs usually requires a high level of interaction, such as exchanging details about the requirements on the intermediate product and the potential specifications for production. In this respect, outsourcing differs substantially from trade in final goods. We therefore formulate the corresponding hypothesis about the effects of intermediate inputs between sectors on a sector's knowledge stock as follows:

Hypothesis 1. The more intense a firm's offshoring relationships with other firms are, and the more innovative those firms are, the higher is the firm-specific innovation activity.

A good representation of how the use of innovations propagates through the production process in a Leontief framework can be found in chapters 3 and 15 of the prominent collection of essays by Scherer (1984). A newer textbook by Greenhalgh and Rogers (2010) motivates the innovation spillovers in such a framework as follows:

> "The basic reason is that in many cases of innovation, one firm's finished product can become part of another firm's production process. Innovation measurement at the level of the firm suggest that product innovations are in the majority, while in the context of the economy they result in a large amount of process innovation. Some examples are new fertilizers that improve the productivity of agricultural production; new weaving machinery that enables the textile industry to create superior fabrics; cash dispensers that allow the banking industry to offer people access to their money at any time of day or night; and new computer software that permits firms in many sectors to organize information more efficiently. (..) The Leontief input-output model already raises the question of which sectors are supplying innovation to which other sectors, creating a relationship between the producers and the users of these innovations. Once these innovation supply relationships are established, there can be many instances where users of innovation feed back information about the product's performance, making suggestions for improvements and this way helping to create the next generation of products they will buy."

The issues named above result in straight suggestions for the scientific analysis by the authorities collecting the patent data. So does the OECD (2009) state that patent statistics are used to map certain aspects of the innovation process like diffusion of technology or technology transfers across industries (e.g. on pages 26 and 91). The importance of these channels of knowledge transfer can be cross-checked using the Community Innovation Statistics (Eurostat, 2010, pp. 142-152). From table 4.2 it is obvious that four out of the five most valuable sources of information for the innovation process can be directly linked to the trade of intermediate products.

The same applies for the question of the most valuable cooperation partners in the innovation process. The cooperation partners from the private sector seem to be more valuable than those from public institutions. Out of the six most important opportunities for joint innovation activities three are directly related to the trade in intermediate products:

Country	Within the enterprise or enterprise group	Clients or customers	Suppliers of equipment, materials, components or software	Competitors or other enterprises of the same sector	Conferences, trade fairs, exhibitions
Belgium	53.3	25.1	28.2	9.6	11.9
Bulgaria	32.2	27.5	28.3	16.6	16.5
Czech Republic	37.4	33.7	24.8	15.9	12.0
Estonia	31.0	17.5	24.6	8.9	9.4
Greece	7.3	16.1	12.7	25.9	12.5
Spain	43.4	16.5	25.1	8.8	7.8
Cyprus	92.6	49.5	80.5	35.7	45.2
Lithuania	29.9	24.4	22.1	8.5	19.1
Luxembourg	65.5	36.5	33.1	21.8	23.6
Hungary	40.5	33.9	21.5	19.8	13.1
Malta	39.5	25.6	23.1	14.4	9.2
Netherlands	42.9	26.7	18.8	8.3	5.2
Austria	60.1	47.7	28.0	20.0	18.3
Poland	53.0	29.3	20.0	17.9	16.3
Portugal	46.1	32.8	26.9	13.5	18.3
Romania	41.8	33.0	34.0	19.3	20.8
Slovenia	57.1	44.8	29.8	20.1	17.4
Slovakia	44.0	28.7	23.0	12.7	12.5
Croatia	43.6	35.2	27.8	15.3	22.4
Turkey	46.3	36.6	29.8	18.2	23.5

Table 4.2: The five most used sources of information 2004-2006 (as a percentage of innovative enterprises).

Source: Eurostat (2010).

cooperation with other enterprises within your enterprise group, cooperation with clients or customers and cooperation with suppliers of equipment, materials, components or software (Eurostat, 2010).

4.3 The data

We use a unique firm-level patent dataset created by a string match of the PATSTAT database edition April 2009 with the Amadeus dataset. PATSTAT contains, among other things, information on title and abstract of a patent application, filing and publication dates of the application, names and origin of the inventors and applicants, and the technological domain of the application according to the international patent classification (IPC). However, it does not contain information about the firms that correspond to the patent applicants. Hence, we match the PATSTAT database with firm-level information from the Amadeus data base. We merge potential patents using semi-automatic string matching based on

Variable	Mean	Std. Dev.	Min	Max
Patent Applications 2007	0.0551	0.4684	0	14
Patent Stock	19.00	138.09	0	5,302
Employees	493.32	657.16	1	4,977
Depreciation	4,895.72	13,345.86	1	508,158
Observations	10255			

Table 4.3: Descriptive statistics.

firm/applicant names. Matching is based on PERL and the output is carefully screened to ensure correct name attribution. This procedure allows us to identify for each firm a stock of registered patents.[3]

To have our results not driven by the high number of small firms which may be innovative but cannot afford the fixed cost of applying for a patent or by a small number of very large firms, we restrict our analysis to German firms with a revenue of more than 3 million Euros in 2007 and eliminate the 5 percent largest firms in terms of revenue. This results in a cross-section of 10,255 firms, of which 1,939 have at least one registered patent. A summary of the data can be found in table 4.3. However, the results are very similar when choosing a different lower cutoff for the revenue, choosing a lower cutoff in terms of employees, or not eliminating outliers in terms of revenue. In the appendix we provide descriptive information on the structure of patenting activity across sectors. More precisely, we report the number of firms in each industry contained in our sample of 10,255 firms, together with the average patent stock of a firm in each industry and the average number of patents applied for in 2007.

4.4 The estimation technique

Spatial econometrics is designed to analyze whether endogenous variables are not only influenced by corresponding exogenous variables, but whether there is some kind of interaction across observations. This interaction might come (1) as a direct influence of the endogenous

[3]The use of patents as a proxy for innovative knowledge comes with a number of difficulties. These difficulties are, amongst others, that the values of patents show a large variance, patenting can be due to other incentives than purely economic ones, and patents do not completely capture the innovative knowledge in a firm. For a discussion of these issues see Griliches (1990) and Basberg (1987). Nevertheless, we see patent statistics as useful indicators for our analysis.

variables of one observation on the endogenous variables of other observations; (2) as a mutual interdependence of the error terms; or (3) as an influence of the exogenous variables of one observation on the endogenous variables of other observations. Equations which are specified to determine the strength of interactions as described in (1) and (2) should not be estimated with standard regression techniques, as left-hand side and right-hand side variables are simultaneously determined. Instead, a specification as in (1) should be estimated using a spatial lag model, while a spatial error model should be used to estimate a specification as in (2).

However, the interaction that we want to identify is characterized as in (3). The weighted patent stock of other firms is an exogenous variable which influences patent output in a certain firm. The reason is that the existing patent stock is determined already in the past. We do not use discounting of past patent activity, so that patents from all years have a weight of one in the construction of a firm's patent stock.[4] The exogeneity of the spatially lagged variable implies that we do not need to use spatial econometric techniques as outlined in the previous paragraph. Instead, we can use a standard estimation strategy. Specifically, due to the count nature of the patent data we use a Poisson model, described in more detail below.

The optimal weighting of observations cannot be determined endogenously from the estimation. This is due to the fact that with cross-sectional data the weighting matrix is a $N \times N$ matrix, where N is the number of observations in the sample. This fact renders it mathematically impossible to estimate this matrix (see eg. Anselin, 1988). Hence, its configuration must be guided by economic theory or intuition.

When using firms as the observational unit, inverse geographical distance between their headquarters is the most often used metric to determine the strength of interaction. However, we argue that innovation spillovers do not accrue from geographical proximity in and of itself. Instead, we believe that outsourcing relationships constitute important sources of firm-interdependence and are crucial in determining innovative activity in a firm. The structure of intermediate goods trade between firms will, thus, guide us in the construction of our weighting matrices.

[4]One might argue that the past patent stock and current patent activity in one period are determined jointly if research effort by sector and input-output linkages remain sufficiently constant over the years. However, there is a high degree of variance over time in these variables.

When constructing a measure of trade in intermediate inputs we differentiate between backward relationships and forward relationships. Backward relationships are a measure for spillovers that move up on the value chain from firms that *use* intermediate inputs to firms that *produce* these intermediate goods. Consequently, each manufacturer of intermediate inputs receives spillovers from all its corporate customers in proportion to the volume of sales. Mathematically spoken, the element w_{ijkl} of the weighting matrix which characterizes spillovers received by firm i in sector k from firm j in sector l is the product of two terms: The first term characterizes the importance of sector l in using intermediate inputs from sector k, measured by the respective value from the input-output matrix relative to all other sectors using products from sector k. The second term characterizes the importance of intermediate inputs for firm j, relative to all other firms of the same sector l. It comes from the Amadeus firm-level database, which contains usage of intermediate inputs for all firms in our sample. This weighting matrix is based on the assumption that all firms in sector l use the same *relative composition* of intermediate inputs, whereas the *absolute* level of intermediate inputs can differ between firms. The bilateral weight of firm j in sector l for firm i in sector k, w_{ijkl}, can hence be written as:

$$w_{ijkl} := \frac{Z_{kl}}{\sum_l Z_{kl}} \cdot \frac{M_j}{\sum_{j \in \mathcal{L}} M_j}, \tag{4.3}$$

where Z_{kl} is the element of the input-output matrix that characterizes inputs produced in sector k and used by sector l, M_j is the volume of intermediate inputs used by firm j, and $\mathcal{L}$ describes the set of firms that operate in sector l. Hence, $\frac{Z_{kl}}{\sum_l Z_{kl}}$ is the relative importance of sector l in using intermediate inputs from sector k, measured by the share over a row of the input-output matrix. Furthermore, $\frac{M_j}{\sum_{j \in \mathcal{L}} M_j}$ is the importance of firm j in using intermediate inputs relative to all other firms in sector l measured by the intermediate inputs used by firm j as a share of total usage of intermediate inputs of firms in that sector l.

The element w_{ijkl} of the weighting matrix for forward spillovers again characterizes spillovers received by firm i in sector k from firm j in sector l and each element of this spillover matrix is defined as the product of two terms: As above, the first term shows the importance of sector l in sending spillovers to sector k, by the value of intermediate inputs used in sector k and produced in sector l divided by the total value of intermediate inputs used in sector k. The second term indicates the importance of firm j relative to all other firms of the same sector l. Since we do not have information on the volume of sales of intermediate inputs, we proxy this number by the revenue of a firm. The second term, thus, is given by the revenue of firm j divided by the sum of revenue of all firms in sector l. This weighting matrix is based on the assumption that the output level of intermediate goods relative to final goods is identical for all firms in one sector and that the relative importance of a firm in purchasing inputs from other firms does not vary within sectors, but only between sectors. Hence, we write the bilateral weight of firm j in sector l for firm i in sector k, w_{ijkl}, as:

$$w_{ijkl} := \frac{Z_{lk}}{\sum_l Z_{lk}} \cdot \frac{R_j}{\sum_{j \in \mathcal{L}} R_j}, \tag{4.4}$$

where Z_{lk} is the element of the input-output matrix that characterizes inputs produced in sector l and used by sector k, R_j is the revenue of firm j, and $\mathcal{L}$ describes the set of firms that operate in sector l. Consequently, the first term $\frac{Z_{lk}}{\sum_l Z_{lk}}$ is the relative importance of sector l in producing intermediate inputs for sector k, measured by the share over a column of the input-output matrix. The second term $\frac{R_j}{\sum_{j \in \mathcal{L}} R_j}$ is our proxy the importance of firm j in producing intermediate inputs relative to all other firms in sector l, measured by the revenue of firm j as a share of total revenue of firms in sector l.

Both of these weighting matrices are potential descriptions of the pattern of knowledge flows due to intermediate goods trade in an economy. In other words, multiplying these weighting matrices with a vector containing the patent stock of all firms yields a potential vector of the knowledge capital that firms can use in their patenting activity. Finding a high correlation of this constructed stock of knowledge capital with actual patent output means that the weighting matrix must indeed be a good representation of actual knowledge flows in the economy.

We assume that spillovers from a firm's own patent stock have a different influence on current patent activity than spillovers from other firms' patent stocks. Thus, we include each firm's own patents as additional explanatory variable in the regression. Apart from their past innovation experience, firms differ with respect to other observable characteristics. Following the specification by Coe and Helpman (1995) introduced in equation (4.1) it is necessary to control for the number of researchers in each firm. Since we do not have data on the composition of workers available we use the stock of employees and the annual capital depreciation in 2007 to control for the capital stock. This allows us to capture all differences between firms which come from their size or their capital-labor ratios, which are highly correlated with research activity. The stock of employees, as well as the capital depreciation, is used in natural logarithms. As additional control variables we use the location of the firm on NUTS 1 level, legal structure, and decade of incorporation (respectively century of incorporation for companies established before 1900). The estimated equation can be written as:

$$p_i \sim Poisson(\mu), \tag{4.5}$$

with

$$\mu = exp(\alpha + \gamma P_i + \rho \sum_{j \neq i} w_{ij} P_j + \delta_1 L_i + \delta_2 K_i + \mathbf{X}\beta + u_i), \tag{4.6}$$

where p_i are patent applications of firm i, P_i is the patent stock of firm i, $\sum_{j \neq i} w_{ij} P_j$ is the weighted patent stock of all other firms j, L_i is the log of firm employees, K_i is the log of depreciations in the firm's balance sheet as proxy for the capital stock, $\mathbf{X}$ is a vector of controls, including dummies for a company's legal form, decade of incorporation, and NUTS 1 location ("Bundesland") as outlined above.[5]

4.5 Results

We estimate six different specifications of the model presented in the previous section. The results of these estimations are presented in table 4.4. All estimations include the control variables outlined above but we do not report all of the coefficients.

The accumulated stock of patents in a firm always positively influences the number of new patents. The estimated coefficient is always significant and in the range between 0.82 and 0.90. This indicates that past innovation is a very good predictor for future innovation. Moreover, we see that the coefficient for employees is positive and significant in all specifications. The estimated coefficient remains surprisingly constant throughout the six columns. This positive coefficient is likely to capture a scale effect from larger firm size. On the other hand, the coefficient for capital is always insignificant. This is evidence that the capital-to-labor ratio does not play a crucial role in the determination of innovative activity.

In the first column we investigate the strength of backward spillovers between firms. We find a positive and significant coefficient of 0.151 which indicates that firms that purchase intermediate inputs have an impact on innovative success in the firms that deliver those intermediate products to them. More precisely, we find that a one unit increase in our

[5] A detailed derivation of this type of estimation equation can be found in Eaton and Kortum (1996) or in the technical appendix of Bottazzi and Peri (2002).

Table 4.4: Estimation results

VARIABLES	(1) Pat 2007	(2) Pat 2007	(3) Pat 2007	(4) Pat 2007	(5) Pat 2007	(6) Pat 2007
Patent stock	0.900***	0.837***	0.840***	0.828***	0.836***	0.823***
	(0.0265)	(0.0285)	(0.0275)	(0.0290)	(0.0267)	(0.0291)
Backward	0.151**					
	(0.0719)					
Bw. inter-industry		0.159**			0.261***	0.244***
		(0.0695)			(0.0666)	(0.0685)
Bw. intra-industry		0.197***				
		(0.0401)				
Forward			0.430***			
			(0.0734)			
Fw. inter-indutry				0.500***	0.701***	0.634***
				(0.106)	(0.0991)	(0.116)
Fw. intra-industry				0.101**		
				(0.0474)		
Intra-industry						0.0550
						(0.0496)
Labor	0.232***	0.232***	0.222***	0.213***	0.223***	0.223***
	(0.0700)	(0.0714)	(0.0710)	(0.0714)	(0.0720)	(0.0722)
Capital	0.00103	0.0291	0.0433	0.0482	0.0360	0.0440
	(0.0521)	(0.0531)	(0.0531)	(0.0532)	(0.0527)	(0.0534)
Constant	-4.684***	-5.597***	-5.790***	-6.411***	-7.830***	-7.786***
	(1.004)	(1.007)	(0.996)	(1.012)	(1.079)	(1.082)
Observations	10,255	10,255	10,255	10,255	10,255	10,255
Pseudo R2	0.5486	0.5543	0.5553	0.5588	0.5614	0.5617
AIC	2401.699	2374.443	2367.05	2351.225	2337.961	2338.713
BIC	2741.769	2721.748	2707.12	2698.53	2685.266	2693.253

Notes: Standard errors in parenthesis. ***Significant at 1 percent level, **Significant at 5 percent level, *Significant at 10 percent level.

measure of backward spillovers increases the number of new patent activities by 15.1%. We then separate the weighting matrix into one that only has positive values for intra-industry intermediate goods trade and has zeros elsewhere, and one which has zeros on the intra-industry elements and the positive values of the backward trade weighting matrix. The coefficients of both weighted patent stocks are now positive and significant, reported in column (2). They have a value similar to the value of the aggregate backward trade weighting matrix.

The specification reported in the third column introduces the weighting matrix that is based on forward trade of intermediate inputs. It tests for the strength of spillovers from firms that produce intermediate inputs to the firms that purchase those inputs to use them in their production process. The estimated coefficient of 0.430 indicates that these forward spillovers are three times more important than backward spillovers. We now perform the same exercise as above, splitting up the weighting matrix into one that only accounts for intra-industry trade and one that only accounts for inter-industry trade. The results presented in column (4) show that inter-industry forward spillovers are substantially more important than intra-industry forward spillovers.

In column (5) we only compare the strength of backward inter-industry spillovers and forward inter-industry spillovers, ignoring the impact of intra-industry spillovers. The resulting pattern is as expected, given the results from column (2) and (4). Forward inter-industry spillovers are substantially stronger than backward inter-industry spillovers. Adding a weighting matrix that accounts only for intra-industry spillovers in column (6) yields an insignificant coefficient for these types of spillovers. This is evidence for the hypothesis that indeed inter-industry spillovers are more important than intra-industry spillovers.

Keller (1998) showed that much of the innovation spillover coefficient in Coe and Helpman (1995) could be explained by random weighting matrices. In order to control for a similar problem we perform robustness checks in which we randomly shuffle the elements of each weighting matrix and repeat the estimation procedure 50,000 times. This strategy yields coefficient estimates that are normally distributed with mean zero. Only a very small share of the estimated coefficients is comparable in size to the estimates we obtain with our weighting matrix as mandated by trade in intermediate inputs.[6]

4.6 Conclusion

In this paper we analyze how intermediate goods procurement relationships can predict the flow of knowledge between industries in Germany. We find evidence that knowledge spillovers do exist and that input-output tables are a good indicator for them.

Differentiating between intra-industry and inter-industry spillovers our estimations show that intra-industry spillovers have no explicative power as soon as we take inter-industry spillovers into account. Using a second dimension of differentiation, the one between forward and backward spillovers, it turns out that forward spillovers seem to be more important than backward spillovers. This result holds when we estimate effects for the more important inter-industry spillovers only or if we account for inter- and intra-industry spillovers jointly.

[6]Detailed results are available from the authors upon request.

Chapter 5

The Structure of Europe: International Input-Output Analysis with Trade in Intermediate Inputs and Capital Flows*

5.1 Introduction

Heckscher-Ohlin theory in its simplest specification (two countries, two goods, two factors) implies that the pattern of production is determined by relative factor endowments and relative factor input coefficients. Under reasonable assumptions, a higher endowment of one factor in country 1 drives up output of the sector that relies extensively on this factor, while output of the other sector declines. If prices of final products remain constant and if the two countries are linked only via trade in final goods, the situation in Country 1 will have no impact on Country 2's output pattern.

However, there are other ways that countries are connected, one of which is capital mobility, especially in highly integrated regions such as the European Union, where barriers to capital mobility have been abolished. Moreover, in recent years there has been a growing tendency toward the international fragmentation of production.[1] Not only final goods but also intermediate inputs are shipped internationally. Purely domestic flows of intermediate

*This chapter is joint work with Mario Larch and Markus Zimmer, forthcoming in the Review of Development Economics. It has also been published as Ifo Working Paper No. 161, 2013.

[1]See, for example, Campa and Goldberg (1997), Hummels et al. (1998), Hummels et al. (2001), Yeats (2001), and Hanson et al. (2005).

products are summarized in a country's input-output accounts, but there are no comparable data for international flows of intermediates. Trefler and Zhu (2005) and Johnson and Noguera (2012) make important contributions toward describing international input-output relationships, but given this new paradigm in the academic treatment of international trade, it is important to expand research in this direction.

In a recent contribution, Fisher and Marshall (2011) show how to calculate Rybczynski effects in a case where the number of sectors exceeds the number of factors empirically observed in an economy. Assuming a Leontieff production technology and constant goods prices, they argue that the Rybczynski effect can be separated into a movement that is orthogonal to the economy's linear production possibility frontier and a second movement along this frontier. The first movement can be uniquely characterized and leads to higher revenue in the economy. The second movement is arbitrary and not relevant for revenue. Hence, it is plausible to argue that the second movement is determined solely by the demand side of the economy, whereas the first can be interpreted as the pure Rybczynski effect as mandated from factor supply.[2]

Fisher and Marshall's (2011) analysis does not consider general equilibrium effects in the form of price changes of final goods. This is because they attempt to provide a framework for calculating Rybczynski derivatives using data reported by official statistical offices, which is characterized by a high number of both sectors and production factors, the former usually exceeding the latter. Deriving production technology from input-output data and employment by sector and under the assumption that one dollar of output indeed has a value of one, they calculate a vector of factor income so that prices mandated by zero profits minimize the sum of squared deviations from a unit vector. Only by coincidence will the mandated price actually be equal to one. However, if production costs are only the best linear fit for actual prices, the effect of price changes on output is everything but straightforward.

Nevertheless, the importance of general equilibrium effects for Rybczynski's (1955) theory cannot be denied. For example, in a recent extension of Rybczynski's ideas, Opp et al. (2009) demonstrate in an analytically tractable model with two large countries, two goods, and two factors, that consumers' low willingness to substitute goods in consumption may lead to a reversion of Rybczynski's classic comparative statics in a setup in which two countries trade

[2]There have already been several attempts to determine a relationship between endowments and outputs (Kohli, 1991; Harrigan, 1997; Fitzgerald and Hallak, 2004). Thompson (2013) estimates the Stolper-Samuelson relationship between changes in wages and changes in goods prices.

with each other, due to adjustments in the terms of trade. The general equilibrium effects on goods prices should be even more pronounced in a one-country analysis of the United States, a large and relatively closed economy. Hence, there is some doubt as to the validity of Fisher and Marshall's (2011) results because changes in output calculated from the production side of the economy may not be compatible with the consumption demand pattern.

With our multicountry extension we address this important shortcoming of the Fisher and Marshall (2011) framework. Our model is characterized by free trade of final consumption goods between 11 European economies. Even the GDP of Germany, the largest economy in our dataset, comprises only little more than a quarter of the total GDP of these 11 countries. This justifies the assumption of a small open economy setup, where output in one country does not affect prices on the common market. Having the baseline scenario characterized by free trade also implies that we do not have to deal with price changes due to changes in trade openness. Moreover, most trade relationships are characterized by exports as well as imports within narrowly defined product classes. This implies a high degree of substitutability between exports and imports in consumption, the opposite of what is required for a reversion of Rybczynski effects in Opp et al. (2009).

Thus, we are confident that our partial derivatives are a reasonable representation of regional Rybczynski effects for small endowment changes. Taking the regional level as a third dimension of analysis (in addition to goods and factors) is especially relevant in light of the current economic imbalances in Europe. Bad economic conditions in the southern economies provide incentives for migration, especially for mobile high-skilled individuals who are able to afford the fixed cost of migration. The resultant changes in regional output patterns may further aggravate the economic downturn in southern economies.

Changes in endowment of labor may be provoked not only by regional economic imbalances, but also by policy measures. Many governments consider attracting high-skilled individuals as an important national policy objective, as for example Germany (BMBF, 2010), because human capital is a major determinant of sustainable growth.[3] This sort of policy includes attracting highly qualified migrants as well as activating the country's "reserves", for example, women (especially mothers) and older persons not currently participating in the labor market due to a lack of public infrastructure (e.g., childcare or vocational training)

[3] This is documented by, for example, Florida (2004) and Trippl and Maier (2010).

Figure 5.1: GDP per capita and high-skilled labor force intensity

Notes: The District of Columbia (United States) does not appear in the figure for ease of display as the GDP per capita is more than double the value of top OECD regions.
Source: OECD (2011).

or because of labor market regulations.[4] When actively engaged in, this type of policy may affect the skill structure of workers in a country, implying a change in the country's relative endowments. Migration-promoting policy measures may even affect relative endowments in two countries. The importance of the skill structure for a high GDP per capita is illustrated in figure 5.1.

We use data from 11 European countries. Employment is differentiated into nine types of labor and the use of capital is tracked for 16 sectors in each country. Moreover, we construct $16 \times 15 = 240$ international bilateral input-output matrices using bilateral trade data from CEPII. This allows us to calculate a 110×176 matrix of factor-sector-country-pair-specific Rybczynski effects, which we aggregate to an 11×11 matrix of bilateral international Rybczynski effects.

When economies are integrated by trade in final products, an additional high-skilled worker is most valuable in Germany and Finland, raising annual output by roughly 33,000 Euros. When the pattern of international trade in intermediate goods is accounted for, the Rybczynski effect in Germany of an additional German high-skilled worker increases

[4]Literature on the impact of immigration on innovative output includes Agrawal et al. (2011), Hunt (2011), Hunt and Gauthier-Loiselle (2010), and Niebuhr (2010). An opposite perspective is taken in the "brain drain" literature, see Brezzi and Piacentini (2010), OECD (2008), and Reiner (2010). Marques and Metcalf (2005) note that policies focused on fostering education and boosting skill levels need to be accompanied by infrastructure improvements. An overview is provided by Solimano (2008).

to 34,500 Euros.[5] Moreover, aggregate output in all other countries is raised by roughly 5,000 Euros. Trade in intermediates does not change the output effect in Finland of a Finish high-skilled worker. However, the introduction of intermediate goods trade imposes a negative output effect of 2,500 Euros in the other countries. Additionally allowing for mobility of capital raises the positive effect of a German high-skilled worker on output in other countries to 10,500 Euros and a Finish high-skilled worker now has a positive externality of 1,500 Euros on output in other countries. In general, high-skilled workers always imply a positive externality in other countries in the case with trade in intermediates and mobile capital, whereas results are mixed when capital is country specific.

The remainder of the paper is organized as follows. In section 5.2 we derive the international Rybczynski matrix, extending Fisher and Marshall's (2011) theory. Section 5.3 explains how we construct our dataset and section 5.4 displays the results. Section 5.5 concludes.

5.2 Derivation of the international Rybczynski matrix

To derive the theoretical properties of the Rybczynski matrix we use a Leontief production function with fixed input coefficients and constant returns to scale. We assume this to be a transnational production function. This means that, potentially, factor inputs from all countries are used to produce final output in one country. Output is given by

$$y_{ik} = \min\left\{\frac{v_{ik11}}{a_{ik11}}, ..., \frac{v_{ikfl}}{a_{ikfl}}, ..., \frac{v_{ikFK}}{a_{ikFK}}\right\} \qquad \forall i = 1, ..., N \text{ and } l = 1, ..., K, \tag{5.1}$$

where y_{ik} is output in country k's sector i and v_{ikfl} is the amount of country l's factor f employed to produce output in country k's sector i and a_{ikfl} is the input coefficient that determines the efficiency of using country l's factor f to produce output in country k's sector i. The number of countries is K while the number of sectors is N and the number of factors is F. A similar relationship holds for all countries k, with the input-coefficients being specific to each country. Full employment, together with the assumption that all production factors

[5] Using a distinct framework but addressing a related question, Caliendo and Parro (2012) demonstrate in a Ricardian gravity model that the trade and welfare effects of NAFTA's tariff reductions are reduced by more than 40% when intermediate goods are not taken into account in production and input-output linkages.

are scarce and have a strictly positive remuneration implies:[6]

$$v_{kf} = \sum_{l=1}^{K} \sum_{i=1}^{N} a_{ikfl} y_{ik} \qquad \forall f = 1, ..., F \text{ and } k = 1, ...K, \tag{5.2}$$

where y_{ik} is output in country k's sector i, v_{kf} is the endowment with factor f in country k and a_{ikfl} is the input coefficient.[7] Since this relationship must hold for any country k, we have $K \times F$ such equations.

In matrix notation for all K times F country-specific production factors this relationship can be written as $\boldsymbol{v} = \boldsymbol{A'y}$, where $\boldsymbol{v}$ is a column vector of length KF, containing information about the factor endowment in all countries, defined as $\boldsymbol{v} = [v_1 \ldots v_K]'$ and each v_k is a column vector of length F. Furthermore, the column vector of final output $\boldsymbol{y}$ is of length KN and defined as $\boldsymbol{y} = [y_1 \ldots y_K]'$, where each y_k is a column vector of length N.

As described by Fisher and Marshall (2011) this can be solved for

$$\boldsymbol{A'} = \boldsymbol{B'C} = \boldsymbol{B'}(\boldsymbol{I} - \boldsymbol{Z})^{-1}, \tag{5.3}$$

where $\boldsymbol{C} = (\boldsymbol{I} - \boldsymbol{Z})^{-1}$ is the matrix of inverse Leontief coefficients which indicates the overall production level necessary to satisfy a unit vector of final demand, given the infinite rounds of intermediate production.[8] $\boldsymbol{I}$ is the identity matrix and $\boldsymbol{Z}$ is a $NK \times NK$ matrix of average intermediate inputs defined as:

$$\boldsymbol{Z} = \begin{bmatrix} Z_{11} & \cdots & Z_{1K} \\ \vdots & \ddots & \vdots \\ Z_{K1} & \cdots & Z_{KK} \end{bmatrix}, \tag{5.4}$$

with each submatrix being of dimension $N \times N$. The matrices on the main diagonal Z_{kk} are, of course, the input-output matrices from the statistical offices, while the matrices off the main diagonal are international input-output matrices. The coefficients of these matrices are fixed Leontief input coefficients but can also be interpreted as those that are optimal for given factor prices and currently prevailing goods prices.

[6]Fisher and Marshall (2011) show that the analysis neither requires scarcity of all production factors nor positive output in all sectors.

[7]For a more flexible production technology, it is the average input coefficient that is optimal to produce each y_{ik} given output prices and factor prices.

[8]Also see Benz et al. (2013) for a detailed derivation of this expression.

Furthermore,

$$\boldsymbol{B} = \begin{bmatrix} B_{11} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & B_{KK} \end{bmatrix} \tag{5.5}$$

is the $NK \times FK$ matrix of direct factor inputs. In our baseline specification, where all production factors are immobile internationally, only the matrices B_{kk} on the main diagonal of $\boldsymbol{B}$ contain positive input coefficients whereas the matrices off the main diagonal are zero because no foreign factors are *directly* used to produce domestic output. In the specification with mobile capital the matrix has dimension $NK \times (F-1)K + 1$ and the last column contains the input of capital which is potentially positive in all rows.

Using the Moore-Penrose pseudoinverse[9] of $\boldsymbol{A'}$ denoted by $(\boldsymbol{A'})^{+}$ it is possible to define a $FK \times NK$ Rybczynski matrix that indicates marginal output responses to marginal changes in factor supply as $\mathrm{d}\boldsymbol{y}/\mathrm{d}\boldsymbol{v} = (\boldsymbol{A}')^{+}$, where the element whose row is indexed by fk and column by il indicates the output effect in country l's sector i caused by a marginal increase in the supply with country k's factor f.

To calculate the aggregate Rybczynski effect of country k's factor f on output in country l, we simply sum over the N columns in a row fk that belong to country l:

$$R_{fkl} = \sum_{i \in \mathcal{L}} \frac{\mathrm{d}y_{il}}{\mathrm{d}v_{fk}}, \tag{5.6}$$

where $\mathcal{L}$ characterizes the set of sectors that belong to country l. To calculate the aggregate Rybczynski effect of all factors in country k on output in country l we further take the sum over all factors f in country k, which can be written as:

$$R_{kl} = \sum_{f \in \mathcal{K}} R_{fkl} = \sum_{f \in \mathcal{K}} \sum_{i \in \mathcal{L}} \frac{\mathrm{d}y_{il}}{\mathrm{d}v_{fk}}, \tag{5.7}$$

where $\mathcal{K}$ characterizes the set of factors that belong to country k. In section 5.4.1 we report the aggregate bilateral Rybczynski effects R_{kl}. However, for the sake of comparison between different specifications of capital mobility in our model, we specify the set of factors $\mathcal{K}$ to comprise labor in country k, but not capital from country k. In section 5.4.2 we report Rybczynski effects R_{fkl} for the factor f of high-skilled workers in each country.

[9]See Moore (1920), Bjerhammar (1951), Penrose (1955), and Albert (1972).

5.3 Database and international input-output matrices

The most important data sources for our analysis are the EU member countries' input-output tables from Eurostat. We use input-output data from 2005 in basic prices, which comprise 59 sectors. We aggregate these data to obtain smaller matrices with 16 sectors. This allows us to merge the input-output data with data on sectoral employment in nine employment categories from Eurostat and capital stocks by sector from EU Klems (O'Mahony and Timmer, 2009). Compared to other sources of internationally harmonized input-output data, such as the OECD Structural Analysis Database (STAN) or the World Input-Output Database (WIOD), the main advantage of using Eurostat data is the availability of information on heterogeneous labor and capital stocks in each sector, which is required for our analysis. Ideally, we would also like to have international input-output tables. In other words, we would like to know the volume of bilateral trade flows from the industry where the product originates to the industry in which the product is used. Since these data are not available, we use a proportionality assumption to calculate the international input-output table as proposed by the OECD[10]

> This technique assumes that an industry uses an import of a particular product in proportion to its total use of that product. For example if an industry such as motor vehicles uses steel in its production processes and 10 per cent of all steel is imported, it is assumed that 10 per cent of the steel used by the motor vehicle industry is imported. (OECD, 2002).

Technically, we calculate the international input-output matrix as $\boldsymbol{Z_{kl}} = \boldsymbol{m_{kl}} \boldsymbol{Z_l} \boldsymbol{q_l}^{-1}$, where $\boldsymbol{Z_{kl}}$ is the international input-output matrix that indicates in its row i and column j flows from country k's sector i to country l's sector j, $\boldsymbol{m_{kl}}$ is a $N \times 1$ vector calculated as imports from country l, $\boldsymbol{Z_l}$ is the $N \times N$ input-output matrix of country l, and $\boldsymbol{q_l}$ is the $1 \times N$ vector of usage of products from all industries in country l.

Bilateral trade data are from the CEPII Baci database. We use a correspondence table from EU RAMON[11] to obtain bilateral trade flows for the 16 sectors described above.

[10]The same or a slightly modified assumption is used by Feenstra and Hanson (1996), Feenstra and Hanson (1999), Hummels et al. (2001), and Yi (2003), among others.
[11]`http://ec.europa.eu/eurostat/ramon/`.

5.4 Results

Following Fisher and Marshall (2011), we compute a full matrix of Rybczynski effects. As explained in section 5.2, this Rybczynski matrix captures differential effects at the sector-factor-country level for 11 countries, 16 sectors, and 10 factors, including nine types of labor plus capital. To highlight the importance of spillovers between countries, we aggregate the individual effects at the country level, resulting in an 11×11 matrix of output effects. In each panel of both tables, we report the sum of effects on all other countries in the last column (indicated by a Σ) as an indicator of the aggregate international Rybczynski. In each panel of both tables, the last row indicates the sum of effects *from* all other countries, also indicated by a Σ. Note that our choice of Σ is also intended to indicate that each element of this column (row) is simply the row (column) sum excluding the element on the main diagonal.

As we are specifically interested in the interdependencies between countries, we present three different scenarios. Our baseline specification assumes free trade in final goods only. In our first extension, we assume a production technology that requires intermediate inputs from abroad in concordance with the international input-output data. This provides an international link, such that changes in factor endowments in one country lead not only to reallocations of factors in this country, but in all countries connected. In a further extension, we relax the assumption of internationally immobile capital and instead consider perfectly mobile capital, not only between sectors of the same economy, but also across countries.

In each of these scenarios we first calculate economy-wide aggregate Rybczynski effects. These Rybczynski effects indicate the additional value of output if an economy is endowed with an additional worker of each type. The economy that experiences the increase in labor endowment is indicated by the row; the resulting output effect in each country is indicated in each column. Output values are in Euros. Thereafter, we calculate Rybczynski effects of an additional high-skilled worker.

5.4.1 Economy-wide Rybczynski effects

Benchmark case: Trade in final goods. In the benchmark case we assume that trade in final goods is free but that on the production side there is no interaction between countries. All factors are immobile internationally and intermediate inputs are sourced only domestically. In technical terms, matrix $\boldsymbol{Z}$ contains only the national input-output matrices Z_{kk} on the diagonal, while all sub-matrices off the diagonal consist of zeros. This implies that endowment changes in an economy do not have repercussions on the output of other economies, neither as to the aggregate value of output, nor as to distribution across sectors.

As highlighted in panel (a) of table 5.1 the own-country effects vary substantially across the 11 countries. The biggest output effect, 712,713 Euros, is found for Denmark and the smallest, 223,005 Euros, for the United Kingdom. Since these numbers indicate the aggregate value of all nine types of labor in the respective economy, they must also correspond to the sum of annual salaries.

Extension 1: Trade in intermediate inputs. In this section, we perform the same exercise with a full matrix $\boldsymbol{Z}$, including national and international input-output data. The international input-output matrices are calculated as described in section 5.3. This implies that producers in all other countries have to adjust their production patterns so as to deliver the intermediate inputs required for production in the country where endowment is increased. Intuitively, for countries that deliver many intermediate products to the respective country, this constraint may prevent them from maintaining the production pattern that maximizes output in the absence of trade in intermediates. However, countries that source a large share of intermediate products from the respective country may even experience an increase in output.

The own-country effects on the main diagonal of table 5.1's panel (b) are usually just marginally smaller than the effects in panel (a). An outlier is Germany, which experiences a decline from $390,062$ to $377,245$ Euros. Also interesting is that the Czech Republic and Slovenia are the two countries that now have a larger Rybczynski effect on own output than was the case in the free trade in final goods only scenario.

Not surprisingly, the effects on other countries differ substantially across countries. These differences are already striking if we look only at the aggregate strength of the effect indicated in the last column of panel (b) in table 5.1, which is simply the sum of effects on all countries other than itself. Clearly, a higher labor endowment in Germany is the situation that is most harmful to the other countries. Aggregate output of all other countries declines even more than it rises in Germany. On the other hand, Slovenia has the smallest negative impact on the other countries, even allowing three of the remaining ten countries to increase their output, namely, Spain, Finland, and Sweden.

Table 5.1: Rybczynski effects of an additional worker of each type

(a) No international interaction

	AT	CZ	DK	ES	FI	GE	IT	NL	SL	SW	UK
AT	616,526	0	0	0	0	0	0	0	0	0	0
CZ	0	283,215	0	0	0	0	0	0	0	0	0
DK	0	0	712,713	0	0	0	0	0	0	0	0
ES	0	0	0	393,156	0	0	0	0	0	0	0
FI	0	0	0	0	563,154	0	0	0	0	0	0
GE	0	0	0	0	0	390,062	0	0	0	0	0
IT	0	0	0	0	0	0	453,329	0	0	0	0
NL	0	0	0	0	0	0	0	702,672	0	0	0
SL	0	0	0	0	0	0	0	0	294,403	0	0
SW	0	0	0	0	0	0	0	0	0	461,120	0
UK	0	0	0	0	0	0	0	0	0	0	223,005

(b) Intermediate input trade

	AT	CZ	DK	ES	FI	GE	IT	NL	SL	SW	UK	Σ
AT	613,193	-1,390	-3,745	-1,093	-2,304	452	-215	-906	-14,496	-1,498	-2,906	-28,100
CZ	-8,338	283,782	-1,995	-733	-1,247	-17,205	-2,115	-5,475	-2,215	-3,317	-3,064	-45,705
DK	-2,028	-1,739	712,561	-1,110	-7,635	-6,031	-1,563	-5,627	-1,270	-38,241	-5,069	-70,314
ES	-6,995	-2,465	-5,442	393,075	-3,544	-12,760	-4,399	-4,168	-6,908	-6,358	-13,611	-66,649
FI	-2,486	-1,151	-6,678	-666	562,554	-1,497	63	-1,432	-1,591	-6,509	-1,236	-23,183
GE	-110,339	-38,692	-50,316	-16,364	-26,831	377,245	-30,017	-61,961	-21,812	-78,683	-46,834	-481,850
IT	-31,776	-6,844	-15,335	-12,022	-12,147	-32,977	448,180	-4,758	-38,848	-22,854	-13,269	-190,830
NL	-10,032	-4,730	-13,625	-3,546	-10,799	-14,181	-4,822	701,280	-6,064	-10,444	-14,878	-93,122
SL	-3,338	-1,060	-325	93	42	-4,227	-10,504	-2,691	295,539	637	-672	-22,046
SW	-4,931	-2,689	-48,981	-1,830	-31,965	-11,687	-3,247	-10,308	-1,533	455,206	-8,917	-126,088
UK	-6,126	-591	-17,059	-6,197	-7,888	-23,892	-6,644	10,770	-1,497	-29,286	222,592	-88,412
Σ	-186,390	-61,351	-163,502	-43,469	-104,318	-124,005	-63,462	-86,558	-96,235	-196,555	-110,457	

(c) Intermediate input trade, mobile capital

	AT	CZ	DK	ES	FI	GE	IT	NL	SL	SW	UK	Σ
AT	713,769	-11,688	-4,391	-1,318	-3,013	1,118	-646	-759	-18,445	-8,528	-3,185	-50,855
CZ	-12,085	308,794	-5,773	-1,962	-3,498	-19,060	-5,919	-4,700	-3,796	-51,113	-3,632	-111,539
DK	-3,604	-62,359	729,318	-1,912	-9,467	-8,714	-4,984	-6,056	-1,566	-81,273	-5,733	-185,667
ES	-7,660	-11,586	-5,643	449,717	-4,305	-13,049	-6,497	-3,993	-9,745	-14,266	-13,700	-90,444
FI	-3,546	-9,619	-7,210	-881	703,412	-19	884	168	-2,575	-20,230	-507	-43,535
GE	-115,656	-51,935	-49,797	-16,871	-31,018	435,671	-35,294	-60,592	-30,509	-101,388	-47,228	-540,286
IT	-32,400	-8,663	-14,673	-12,119	-13,730	-33,736	535,994	-4,758	-51,322	-29,899	-13,375	-214,675
NL	-10,782	-15,003	-13,166	-3,500	-11,659	-10,712	-4,526	683,659	-7,147	-20,842	-13,389	-110,727
SL	-4,061	-6,673	-1,922	-38	-998	2,263	6,375	-1,244	388,613	-2,344	-309	-8,951
SW	-7,110	-26,632	-55,151	-2,550	-43,414	-12,733	-4,795	-10,441	-2,861	796,891	-9,217	-174,904
UK	-6,611	-6,390	-17,097	-6,195	-9,125	-23,049	-6,964	11,460	-2,694	-40,808	253,292	-107,472
Σ	-203,514	-210,549	-174,823	-47,345	-130,226	-117,692	-62,365	-80,914	-130,662	-370,690	-110,274	

In the last row of table 5.1's panel (b) we report the aggregate impact experienced by a country, which must be understood as the output effect in one country if all other countries undergo an increase in labor endowment. Hence, by construction it is equal to the sum over all rows of a column, excluding the element on the main diagonal. This effect is largest for Austria and Sweden, mostly driven by a very strong negative effect when endowment in Germany is increased. The country least affected by such a European-wide change is Spain, indicating that Spain is not an important producer of intermediate inputs.

The regional distribution of effects is also very heterogeneous. Endowment increases in Denmark and Spain have a very similar aggregate impact on all other countries. However, whereas in the case of Denmark, it is Sweden that suffers most, accounting for more than half the aggregate effect, a higher labor endowment in Spain affects many countries very similarly, with the United Kingdom and Germany being the two that suffer most.

Extension 2: Mobile capital. In panel (c) of table 5.1 we report results for the same exercise, but with a further channel of international interaction. We now assume capital to be internationally mobile. This means that instead of $11 \times 10 = 110$ production factors, we now have only $11 \times 9 + 1 = 100$, that is, nine types of labor in each country plus mobile capital. Interestingly, output effects in some countries change substantially with the introduction of this additional channel, whereas output changes in other countries seem to be driven by capital movements to a much smaller extent than they are by trade in intermediate inputs.

Looking first at the main diagonal, the biggest change compared to panel (b) occurs for Sweden, which seems to benefit from huge capital inflows as a response to a higher endowment with labor. Other elements on the main diagonal that change substantially are those for Finland and Slovenia. An interesting case is the Netherlands. This country experiences less of an increase in output when it has a higher labor endowment and mobile capital than it does in the case of immobile capital. This finding indicates that returns to capital in the Netherlands are so low that the liberation of capital flows leads to an outflow of capital, even when labor endowment rises.

In the last column of table 5.1's panel (c), where the aggregate effect on other countries is reported, we find large changes, compared to panel (b), for the Czech Republic and Denmark. A higher labor endowment in these countries seems to attract a great deal of capital from other countries, making these countries smaller in terms of output. Interestingly, these large capital flows do not result in much output change in the Czech Republic and Denmark themselves, compared to the case where capital is immobile, indicating that capital is used relatively less efficiently in these two countries. Both countries attract a high amount of capital from Sweden, and Denmark also attracts a great deal of capital from the Czech Republic.

Logically, Sweden and the Czech Republic are also the countries that suffer most from aggregate increases in the labor endowment of all other countries, not only in comparison with panel (b) but also in absolute terms. Both countries experience a huge negative Rybczynski effect from endowment changes, and the effect is similar to that observed in the case of immobile capital. Rybczynski effects originating from the Czech Republic and Denmark have the largest impact on Sweden, while Rybczynski effects originating from Denmark and Sweden have the largest effect on the Czech Republic. The difference between the results in table 5.1's panel (b) and (c) implies large capital flows between these countries.

5.4.2 Professionals

What is the effect of high-skilled workers on production in countries integrated by intermediate goods trade and/or mobile capital? From a public policy perspective, this question is of special interest. Countries invest in their public education systems to increase the share of high-skilled workers in the population and immigration legislation in many countries is biased toward the high-skilled. Within Europe, where there are no barriers to international migration, high-skilled people are generally more mobile than the low-skilled. With our analysis, we can provide a detailed answer to the question of what a change in the number of high-skilled workers in one or more European countries implies for output in each other country.

The labor category in our data that is most likely to include high-skilled workers is that of "Professionals" as classified by the ISCO-88 system. "Professionals increase the existing stock of knowledge, apply scientific or artistic concepts and theories, teach about the foregoing in a systematic manner, or engage in any combination of these three activities. Most occupations in this major group require skills at the fourth ISCO skill level." (ILO, 2013). Thus, in the following we report Rybczynski effects for Professionals for the same three specifications of international interaction as in section 5.4.1.

Benchmark case: Trade in final goods. We again begin with our benchmark scenario: free trade in final goods. Contrary to our findings above, we now see negative figures on the main diagonal of table 5.2's panel (a) for some countries. These negative Rybczynski effects seem counterintuitive at first glance. However, the logic of the Rybczynski theorem implies that every additional Professional must draw off resources from other sectors. The negative effect in some sectors may dominate the positive effect in other sectors, yielding an aggregate negative coefficient.[12]

[12]For more information on negative coefficients of this type, see Fisher and Marshall (2011). Their OLS estimation of factor rewards is identical to our calculation of aggregate Rybczynski effects. They find a positive reward for professional occupations in the United States, but a negative reward for education and

Table 5.2: Rybczynski effects of an additional professional

(a) No international interaction

	AT	CZ	DK	ES	FI	GE	IT	NL	SL	SW	UK
AT	12,819	0	0	0	0	0	0	0	0	0	0
CZ	0	-10,588	0	0	0	0	0	0	0	0	0
DK	0	0	-23,470	0	0	0	0	0	0	0	0
ES	0	0	0	27,169	0	0	0	0	0	0	0
FI	0	0	0	0	32,864	0	0	0	0	0	0
GE	0	0	0	0	0	32,990	0	0	0	0	0
IT	0	0	0	0	0	0	-79,687	0	0	0	0
NL	0	0	0	0	0	0	0	7,779	0	0	0
SL	0	0	0	0	0	0	0	0	4,406	0	0
SW	0	0	0	0	0	0	0	0	0	-79,788	0
UK	0	0	0	0	0	0	0	0	0	0	21,196

(b) Intermediate input trade

	AT	CZ	DK	ES	FI	GE	IT	NL	SL	SW	UK	Σ
AT	13,052	-1,058	175	-1	-46	-1,118	1,761	12	485	-939	0	-729
CZ	-643	-10,582	-29	-71	-106	-504	-93	-241	-19	222	-98	-1,582
DK	64	-98	-23,473	10	55	-162	-223	-32	20	-741	-11	-1,120
ES	363	-582	718	27,188	-15	-170	3,459	76	408	-381	135	4,012
FI	27	-62	534	-10	32,858	-308	483	-32	11	-3,195	94	-2,457
GE	2,972	-768	2,312	118	-337	34,452	-2,350	-659	-46	3,729	49	5,021
IT	3,276	-308	1,915	918	489	915	-82,223	416	3,305	774	603	12,303
NL	-99	-1,238	840	-35	-227	-1,304	1,395	7,735	118	-1,867	403	-2,015
SL	-17	372	46	-4	-12	197	-4,201	-128	4,332	10	-119	-3,948
SW	37	-8	3,373	5	-591	-51	-383	-248	-26	-78,055	-116	1,990
UK	361	-1,628	341	121	-393	136	-346	245	-266	-971	21,067	-2,399
Σ	6,341	-5,378	10,134	1,051	-1,182	-2,368	-499	-591	3,989	-3,360	940	

(c) Intermediate input trade, mobile capital

	AT	CZ	DK	ES	FI	GE	IT	NL	SL	SW	UK	Σ
AT	3,882	479	658	2	-44	-1,287	1,806	44	627	153	13	2,451
CZ	-295	-14,481	6,682	-35	-64	-480	-929	-29	42	8,621	-85	13,428
DK	267	9,399	-47,641	44	96	7	-1,186	63	29	6,930	-75	15,574
ES	435	844	1,132	25,639	-4	-169	2,995	124	513	985	154	7,009
FI	81	1,224	1,122	-14	31,273	-486	966	77	49	-1,739	223	1,504
GE	3,438	1,325	1,884	134	-286	34,209	-3,644	-303	275	7,667	100	10,590
IT	3,367	-1	1,506	917	507	978	-65,102	458	3,735	2,109	577	14,154
NL	0	489	1,144	-40	-196	-1,471	1,359	1,387	161	-47	471	1,870
SL	-286	1,145	358	-65	-10	-457	3,272	-22	930	20	104	4,059
SW	169	3,646	5,546	13	-589	-157	-523	-112	11	-137,953	31	8,034
UK	397	-702	440	106	-364	70	-414	311	-216	1,045	19,462	673
Σ	7,572	17,848	20,472	1,061	-954	-3,451	3,701	612	5,228	25,744	1,513	

healthcare occupations. The ISCO-88 class of Professionals includes science and engineering professionals, health professionals, teaching professionals, business and administration professionals, information and communications technology professionals, and legal, social, and cultural professionals.

Extension 1: Trade in intermediate inputs In the first extension, reported in panel (b) of table 5.2, we add intermediate goods trade. Above, when endowment with all factors is increased, the introduction of trade in intermediates leads to smaller positive output effects in the own country, compared to the situation with only trade in final goods. This is no longer the case; instead, the impact of trade in intermediates on the Rybczynski effects can go in either direction.

Another difference from the case above is that effects on other countries are now more often positive. Italy, Germany, Spain, and Sweden even have an aggregate positive effect on all other countries. Denmark is the country that gains most from an increase in the endowment with Professionals in all other countries, only losing from a higher endowment in the Czech Republic (and in Denmark itself). Other countries that gain from such a change are Austria, Slovenia, Spain, and the United Kingdom. The country that loses most is Sweden, mostly caused by a negative Rybczynski effect with Professionals in Finland. We conclude that a higher number of high-skilled workers often implies positive spillovers on output in other countries when capital is immobile.

Extension 2: Mobile capital. Assuming capital to be perfectly mobile implies some important changes in the picture painted previously as shown in table 5.2's panel (c). The only country that benefits more from a higher endowment of high-skilled labor than in the case with immobile capital is Italy. More precisely, it is the only one that is harmed less: the Rybczynski effect is now $-65,102$ instead of $-82,223$ Euros as it was above. The Rybczynski effect of high-skilled workers in all other countries on their own output is smaller than found above. The effect is smaller at the expense of a generally higher effect on other countries' output when capital is mobile. In fact, summing over all other countries gives positive aggregate Rybczynski effects for high-skilled workers in all countries. The countries that cause the largest effect on all other countries are Denmark, Italy, the Czech Republic, and Germany. All of them have a very high impact on output in Sweden, which is the country that gains most from aggregate changes in all other countries. Moreover, only one country – Germany – is affected negatively by a higher endowment with high-skilled in all other countries. This is an interesting result since it suggests that capital flows out of the country where endowment with high-skilled workers is increased. This means that sectors that are relatively high-skilled-labor-intensive and, hence, expand as a result of the endowment shock, seem to be using relatively little capital. The sectors in which output is reduced must be relatively capital-intensive, allowing capital to flow out to other countries. Compared to the situation with immobile capital, the positive spillovers of high-skilled workers on output in other countries are even larger.

5.5 Conclusion

This paper makes a two-fold contribution to the literature. First, we theoretically derive a method to calculate a matrix of international bilateral Rybczynski effects using data from only the supply side of the economy. The international Rybczynski effect is the aggregate output change in one country given that endowment with one or more factors in another country increases. Second, based on this matrix, we describe the economic structure of 11 EU countries. We begin by assuming free trade in final goods and gradually introduce two channels of international interaction: trade in intermediate inputs and international mobility of capital.

We find that all countries increase their output when they obtain an additional unit of each type of labor. When introducing traded intermediate inputs, the bilateral effects on other countries are mostly negative and the aggregate effect that endowment changes in one country have on the sum of output changes in all other countries is always negative. When we additionally introduce internationally mobile capital, the pattern remains qualitatively the same. However, Rybczynski effects on output in the own country are generally larger and Rybczynski effects on output in other countries are generally larger in absolute terms, which implies flows of capital into the country where endowment of all other factors is raised.

Calculating Rybczynski effects for high-skilled Professionals, we find that some countries lose in terms of output from such a change. This negative effect is caused by the fact that a higher endowment with one factor implies movements of other factors between sectors and a different production volume of intermediate inputs, which may also imply movements into sectors where factors or intermediate inputs are less productive.[13] The international integration of the production process through intermediate inputs leads to a large number of positive spillover Rybczynski effects on other countries. For some countries, even the aggregate effect on the "rest of the world" is positive. Assuming capital to be perfectly mobile implies mostly smaller effects on output in the own country and larger effects on output in other countries. The aggregate effect on the sum of all other countries is now

[13]Having calculated an economy-wide rate of return for each factor, sectors with less productive factors are those where the implied cost of production exceeds the value of output.

positive for all countries. This is caused by an outflow of capital as a response to a higher endowment with high-skilled Professionals.

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Appendix A

Appendix to Chapter 1

Proof of proposition 4. We prove part (1) of this proposition by assuming an equilibrium with high β and analyzing its stability. After that we show that no other equilibria are possible given that the one-way task trade equilibrium is stable. Defining $t(I^*) := \beta \int_0^{I^*} \tau(i) - \beta^{-1} \mathrm{d}i$, such an equilibrium with task concentration in the labor-abundant foreign economy is described by

$$
\begin{aligned}
L &= (1 - I^*) \frac{nx}{a} && \text{(A.1)} \\
L^* &= \frac{n^* x^*}{a^*} \left[1 + (\alpha^* - 1) I^* + \alpha^{* \frac{\theta - 1}{\theta}} \alpha^{\frac{1}{\theta}} \left(I^* + t(I^*) \right) \right] && \text{(A.2)} \\
c &= \frac{w}{a} \left[1 + \left(\frac{w^* \alpha}{w} - 1 \right) I^* + \frac{w^* \alpha}{w} t(I^*) \right] && \text{(A.3)} \\
c^* &= \frac{w^*}{a^*} \left[1 + (\alpha^* - 1) I^* \right] && \text{(A.4)} \\
\beta \tau(I^*) &= \frac{w}{w^* \alpha} && \text{(A.5)}
\end{aligned}
$$

plus the conditions for final goods market clearing and full employment of managers in either country, and determination of salaries from equations (1.1), (1.2), and (1.3).

$L^*/L > 1$ and $nx = n^* x^*$ imply

$$L^*/L = 1 + \frac{2^{1-\theta} I^* + 2^{-\theta} t(I^*)}{1 - I^*} > 1. \quad \text{(A.6)}$$

Since $L^*/L = 1$ for $I^* = 0$ and the right-hand side strictly increasing in I^*, $L^*/L > 1$ requires $I^* > 0$. With $\beta > 1/\alpha = 2^\theta$, equation (A.5) mandates $w > w^*$. This type of equilibrium is always stable because home firms prefer offshoring over domestic production for all tasks $i \leq I^*$ if foreign firms do not change the location of production (see equation (A.5)). Moreover, a strategy to set up a production site in the home country and deliver to *all, home and foreign,* firms is not profitable. This is shown by the observation that aggregate production costs in the home economy, inclusive of offshoring costs, are greater or equal than aggregate production costs in the foreign economy, or

$$\frac{w\left(nx+\beta\tau(i)n^*x^*\right)}{A} \geq \frac{w^*\left(n^*x^*+\beta\tau(i)nx\right)}{A}\,\forall\, i \tag{A.7}$$

as long as $w \geq w^*$. Such a strategy is called global deviation by Grossman and Rossi-Hansberg (2012). No other offshoring pattern can satisfy the full employment condition in equation (A.6). This proves that the equilibrium described above is unique.

Now we turn to case (2) where $\beta < 2^\theta$. Exploiting $nx = n^*x^*$, we define a cutoff endowment proportion L^*/L denominated by Λ which is characterized by equalized wages $w = w^*$ and one-way task trade with concentration in the foreign economy, or

$$\Lambda := 1 + \frac{2^{1-\theta}\tilde{I}^*(1,\beta) + 2^{-\theta}t\left(\tilde{I}^*(1,\beta)\right)}{1-\tilde{I}^*(1,\beta)}. \tag{A.8}$$

where $\tilde{I}^*(w/w^*,\beta) := \tau^{-1}\left[(w/w^*)(2^\theta/\beta)\right]$ is the solution to equation (A.5), expressed as a function of the relative production wage and the cost of offshoring. Obviously, this function is well defined only for values $\tilde{I}^*(\cdot) \in [0,1]$.[1] It can be seen from equation (A.5) that $\tilde{I}^*(\cdot)$ as well as the entire right-hand side of equation (A.8) are increasing in w/w^*, so that $L^*/L > \Lambda$ implies ceteris paribus $w > w^*$. The arguments for stability and uniqueness from above apply here as well. This means that a sufficiently disproportionate labor endowment yields a unique equilibrium with one-way offshoring, even if technological offshoring costs β are low. With $L^*/L = \Lambda$, wages in the two countries are equalized $w = w^*$ but any change in the pattern of task trade is still refuted by the fact that local and global deviation conditions still hold and no other equilibrium would fulfill the full employment condition under equalized wages. Hence, we still see one-way offshoring with concentration of all tasks $i \in [0, I^*]$ in the foreign economy.

Finally, in a case where $1 < L^*/L < \Lambda$ an equilibrium with one-way task trade is not stable, given the full employment conditions under one-way task trade. On the one hand,

[1] It is impossible to derive a closed form solution for the equilibrium cut-off value I^*, but nor is it necessary to do so for a proof of the proposition.

complete foreign concentration would require $w < w^*$ because the function $\tilde{I}^*(w/w^*, \beta)$ would have to take a smaller value than $\tilde{I}^*(1, \beta)$. However, then it would be subject to global deviation as defined in equation (A.7). At given factor prices, shifting the entire production to the home economy leads to lower aggregate production costs. On the other hand, complete home concentration is not possible either because it would require $L^*/L < 1$. Hence, only an equilibrium with equal wages $w = w^*$ can be stable, featuring positive levels of offshoring since $\beta < 2^\theta$. Given the endowment proportion in this equilibrium, it can be seen from equation (A.8) that less than all tasks $i \in \left[0, \tilde{I}^*(1, \beta)\right]$ need to be concentrated in the foreign country. Hence, the equilibrium must feature two-way task trade so that full employment is satisfied and there exist an infinite number of ways in which the interval may be split into subintervals hosted by the foreign and the home economy so that the full employment conditions for both countries hold. In this sense, the pattern of task concentration is indeterminate.[2] □

[2] This indeterminacy resembles the well-known "Melvin indeterminacy" which arises in factor price equalization equilibria for Heckscher-Ohlin models where the number of goods exceeds the number of factors.

Appendix B

Appendix to Chapter 2

B.1 Proofs

Proof of Lemma 5. Relative changes in the offshoring savings factor are given by

$$\hat{\Theta}(I) = \frac{(\sigma-1)\mu(I)^2 I - (\sigma-1)(r+g+m)\Big(\mu'(I)I + \mu(I)\Big)}{\Big((\sigma-1)(r+g+m) + \mu(I)I\Big)(\sigma-1)(r+g+m)}\mathsf{d}I$$
$$> \left(\frac{(\sigma-1)\mu(I)^2 I - (\sigma-1)(r+g+m)\mu'(I)I}{\Big((\sigma-1)(r+g+m) + \mu(I)I\Big)(\sigma-1)(r+g+m)} - 1\right)\mathsf{d}I \tag{B.1}$$

where the inequality in the second line follows from the fact that the denominator is larger than $(\sigma-1)(r+g+m)\mu(I)$ because $(\sigma-1)(r+g+m) > (1-I)\mu(I)$. Adding the expression for relative changes in total offshoring costs from equation (2.51) yields

$$\hat{\Psi}(I) > \frac{\nu'(I)(1-I)(\sigma-1)^2(r+g+m)^2 + \nu(I)^2(\sigma-1)(r+g+m)\left(I(\sigma-1)-\sigma\right)}{\Big((\sigma-1)(r+g+m)-(1-I)\mu(I)\Big)\Big(I\mu(I)+(\sigma-1)(r+g+m)\Big)(\sigma-1)(r+g+m)}\mathsf{d}I$$
$$+ \frac{\nu(I)I(1-I)(\sigma-1)\left(\nu'(I)(r+g+m)-\nu(I)^2\right)}{\Big((\sigma-1)(r+g+m)-(1-I)\mu(I)\Big)\Big(I\mu(I)+(\sigma-1)(r+g+m)\Big)(\sigma-1)(r+g+m)}\mathsf{d}I - \mathsf{d}I \tag{B.2}$$

where the second order condition for optimality in equation (2.14) can be used to show that the numerator of the first line is larger than $-\mu(I)^2 I(\sigma-1)(r+g+m)$ and the numerator of the fraction in the second line is larger than $\mu(I)^3 I(1-I)$. This allows to cancel the first term of the denominator which yields

$$\hat{\Psi}(I) > -\frac{\mu(I)^2 I}{\Big(I\mu(I)+(\sigma-1)(r+g+m)\Big)(\sigma-1)(r+g+m)}\mathsf{d}I - \mathsf{d}I \tag{B.3}$$

Using equation (2.17) this can be written as

$$\hat{\Psi}(I) > -\frac{I}{1-I}\mathsf{d}I - \mathsf{d}I$$
$$= -\frac{\mathsf{d}I}{1-I} \tag{B.4}$$

□

B.2 Robustness checks

Table B.1: Robustness check 1: Export data over manufacturing value added

	$\sigma = 3.8,\ R = 0.05$		$\sigma = 3.8,\ R = 0.1$		$\sigma = 5,\ R = 0.05$		$\sigma = 5,\ R = 0.1$	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
alpha	0.35***	0.30***	0.70***	0.59***	0.57***	0.44***	1.14***	0.88***
	(0.02)	(0.05)	(0.04)	(0.09)	(0.04)	(0.09)	(0.09)	(0.19)
beta	3.92***	4.27***	3.92***	4.27***	5.03***	5.53***	5.03***	5.53***
	(0.07)	(0.33)	(0.07)	(0.33)	(0.12)	(0.45)	(0.12)	(0.45)
ln of		-0.12		-0.12		-0.21		-0.21
		(2.03)		(2.03)		(2.01)		(2.01)
$(ln\ of)^2$		0.09		0.09		0.06		0.06
		(0.55)		(0.55)		(0.55)		(0.55)
$(ln\ of)^3$		0.02		0.02		0.02		0.02
		(0.07)		(0.07)		(0.07)		(0.07)
$(ln\ of)^4$		0.00		0.00		0.00		0.00
		(0.00)		(0.00)		(0.00)		(0.00)
Country FE	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Observations	456	456	456	456	456	456	456	456
Adjusted R^2	0.765	0.799	0.765	0.799	0.765	0.799	0.765	0.799

Notes: Endogenous variable is the ratio of Chinese exports of intermediate inputs to OECD countries over the countries' manufacturing value added. Constant and fixed effects not reported. Standard errors in parenthesis. ***Significant at 1 percent level, **Significant at 5 percent level, *Significant at 10 percent level.

Table B.2: Robustness check 2: Import data over GDP

	$\sigma = 3.8,\ R = 0.05$		$\sigma = 3.8,\ R = 0.1$		$\sigma = 5,\ R = 0.05$		$\sigma = 5,\ R = 0.1$	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
alpha	0.48***	0.51***	0.97***	1.02***	0.87***	0.94***	1.75***	1.88***
	(0.00)	(0.01)	(0.01)	(0.02)	(0.01)	(0.02)	(0.02)	(0.04)
beta	3.90***	3.85***	3.90***	3.85***	5.13***	5.06***	5.13***	5.06***
	(0.01)	(0.02)	(0.01)	(0.02)	(0.01)	(0.02)	(0.01)	(0.02)
ln of		9.35***		9.35***		9.28***		9.28***
		(3.35)		(3.35)		(3.34)		(3.34)
$(ln\ of)^2$		2.24***		2.24***		2.23***		2.23***
		(0.78)		(0.78)		(0.78)		(0.78)
$(ln\ of)^3$		0.23***		0.23***		0.23***		0.23***
		(0.08)		(0.08)		(0.08)		(0.08)
$(ln\ of)^4$		0.01***		0.01***		0.01***		0.01***
		(0.00)		(0.00)		(0.00)		(0.00)
Country FE	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Observations	602	602	602	602	602	602	602	602
Adjusted R^2	0.744	0.777	0.744	0.777	0.744	0.777	0.744	0.777

Notes: Endogenous variable is the ratio of OECD countries' imports of intermediate inputs from China over the countries' GDP. Constant and fixed effects not reported. Standard errors in parenthesis. ***Significant at 1 percent level, **Significant at 5 percent level, *Significant at 10 percent level.

Table B.3: Robustness check 3: Export data over GDP

	$\sigma = 3.8,\ R = 0.05$		$\sigma = 3.8,\ R = 0.1$		$\sigma = 5,\ R = 0.05$		$\sigma = 5,\ R = 0.1$	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
alpha	0.49***	0.49***	0.97***	0.98***	0.88***	0.88***	1.76***	1.77***
	(0.00)	(0.03)	(0.01)	(0.05)	(0.01)	(0.07)	(0.02)	(0.14)
beta	3.90***	3.90***	3.90***	3.90***	5.13***	5.12***	5.13***	5.12***
	(0.01)	(0.08)	(0.01)	(0.08)	(0.01)	(0.10)	(0.01)	(0.10)
ln of		3.83		3.83		3.78		3.78
		(3.89)		(3.89)		(3.88)		(3.88)
$(ln\ of)^2$		0.99		0.99		0.98		0.98
		(0.83)		(0.83)		(0.83)		(0.83)
$(ln\ of)^3$		0.11		0.11		0.11		0.11
		(0.08)		(0.08)		(0.08)		(0.08)
$(ln\ of)^4$		0.00		0.00		0.00		0.00
		(0.00)		(0.00)		(0.00)		(0.00)
Country FE	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES
Observations	538	538	538	538	538	538	538	538
Adjusted R^2	0.738	0.762	0.738	0.762	0.738	0.762	0.738	0.762

Notes: Endogenous variable is the ratio of Chinese exports of intermediate inputs to OECD countries over the countries' GDP. Constant and fixed effects not reported. Standard errors in parenthesis. ***Significant at 1 percent level, **Significant at 5 percent level, *Significant at 10 percent level.

Appendix C

Appendix to Chapter 3

Proof to lemma 4. The partial derivative of A with respect to m is given by

$$\frac{\partial A}{\partial m} = \frac{\sigma(1-I)\gamma\mu(I)\bar{\mu}A}{(r+g+m)\Big((r+g+m)(\sigma-1)-(1-I)\gamma\mu(I)\bar{\mu}\Big)} - \frac{(\sigma-1)A}{(r+g+m)(\sigma-1)+I\gamma\mu(I)\bar{\mu}} - \frac{gA}{m(g+m)} > 0 \tag{C.1}$$

where the inequality requires that

$$I < \frac{1}{\sigma+2} \tag{C.2}$$

The partial derivative of A with respect to g is given by

$$\frac{\partial A}{\partial g} = \frac{A\left((r+g+m)^2(\sigma-1)^4 + \Big((\sigma I + (1-I)\Big)(r+g+m)(\sigma-1)^2\gamma\mu(I)\bar{\mu}\right)}{\Big((r+g+m)(\sigma-1)-(1-I)\gamma\mu(I)\bar{\mu}\Big)\Big((r+g+m)(\sigma-1)+I\gamma\mu(I)\bar{\mu}\Big)} + \frac{A\Big(r(r+g)+m(g+m)-(\sigma-2)(r+g)(g+m)\Big)}{(r+g+m)(r+g)(g+m)} \tag{C.3}$$

which is positive whenever $I \leq 0.5$ and

$$(2+(\sigma-1)I)(r+g+m)(\sigma-1)^2 > \sigma - 2 - \frac{r}{g+m} \tag{C.4}$$

and a sufficient condition for this expression can be given as

$$(r+g+m)(\sigma-1) > \frac{1}{2} \tag{C.5}$$

The partial derivative of A with respect to I is given by

$$\frac{\partial A}{\partial I} = \frac{A\sigma\gamma\bar{\mu}\Big(\mu(I) - (1-I)\mu'(I)\Big)}{(r+g+m)(\sigma-1) - (1-I)\gamma\mu(I)\bar{\mu}} - \frac{A\gamma\bar{\mu}\Big(\mu(I) + I\mu'(I)\Big)}{(r+g+m)(\sigma-1) + I\gamma\mu(I)\bar{\mu}} - \frac{\mu(I)A}{\int_0^I \mu(i)\mathsf{d}i} \tag{C.6}$$

which is negative whenever $r+g+m > \int_0^I \mu(i)\mathsf{d}i$, $(\sigma-1)I(1-I)\mu'(I) > (\sigma I + 1 - I)\mu(I)$, and $\Big(\sigma(1-I)+I\Big)\mu'(I)\int_0^I \mu(i)\mathsf{d}i > (1-2I)\mu(I)^2$ which sets limits to the structure of the imitation leakage function and the feasible levels of offshoring. □

Appendix D

Appendix to Chapter 4

Table D.1: **List of sectors, firms, and their patenting activity.**

CPA (2002)	Sector	Firms	Av. Patent Stock	Av. Patents 2007
01	Products of agriculture, hunting and related services	22	0.05	0.0000
02	Products of forestry, logging and related services	2	0.00	0.0000
10	Coal and lignite; peat	4	3.25	0.0000
11	Crude petroleum and natural gas; services incidental to oil and gas extraction, excluding surveying	6	9	0.0000
12	Uranium and thorium ores	1	5	0.0000
13	Metal ores	2	14	0.0000
14	Other mining and quarrying products	18	5.28	0.0000
15.1-8	Food products	276	2.08	0.0036
15.9	Beverages	51	1.25	0.0000
16	Tobacco products	7	4.57	0.0000
17	Textiles and textile products	58	26.34	0.0862
18	Wearing apparel; furs	43	3.42	0.0000
19	Leather and leather products	11	10.36	0.0000
20	Wood and products of wood and cork (except furniture); articles of straw and plaiting materials	60	14.17	0.1500
21.1	Pulp, paper and paperboard	57	14.00	0.0702
21.2	Articles of paper and paperboard	61	19.85	0.0491
22.1	Books, newspapers and other printed matter and recorded media	45	1.89	0.0000
22.2-3	Printing services and services related to printing; reproduction services of recorded media	5	6.00	0.0000
23	Coke, refined petroleum products and nuclear fuel	23	3.39	0.0000
24.4	Pharmaceuticals, medicinal chemicals and botanical products	84	48.17	0.0952
24 w/o 24.4	Chemicals, chemical products and man-made fibres (except pharmaceuticals)	198	54.37	0.1818
25.1	Rubber products	34	31.32	0.1765
25.2	Plastic products	176	44.33	0.2102
26.1	Glass and glass products	30	11.67	0.0000
26.2-8	Other non metallic mineral products (except glass)	87	91.67	0.1149
27.1-3	Basic iron and steel and ferro alloys, tubes and other first processed iron and steel	76	25.80	0.0921
27.4	Basic precious metals and other non-ferrous metals	54	22.31	0556
27.5	Foundry work services	59	14.88	0.0339
28	Fabricated metal products, except machinery and equipment	328	60.72	0.2012
29	Machinery and equipment n.e.c.	645	106.76	0.2202
30	Office machinery and computers	66	77.67	0.5455
31	Electrical machinery and apparatus n.e.c.	209	55.26	0.2584
32	Radio, television and communication equipment and apparatus	19	109.84	0.0526

CPA (2002)	Sector	Firms	Av. Patent Stock	Av. Patents 2007
33	Medical, precision and optical instruments; watches and clocks	135	129.38	0.3778
34	Motor vehicles, trailers and semi-trailers	127	40.18	0.2913
35	Other transport equipment	48	31.38	0.1250
36	Furniture; other manufactured goods n.e.c.	84	36.87	0.0714
37	Secondary raw materials	24	1.00	0.0000
40.1,3	Production and distribution services of electricity; Steam and hot water supply services	313	1.3327	0.0032
40.2	Manufactured gas and distribution services of gaseous fuels through mains	64	0.63	0.0000
41	Collected and purified water; distribution services of water	35	1.11	0.0000
45.1-2	Site preparation work and works for complete construction or parts thereof; civil engineering work	195	6.53	0.0051
45.3-5	Building installation and completion work; renting services of construction or demolition equipment with operator	110	18.40	0.0545
50	Trade, maintenance and repair services of motor vehicles and motorcycles; retail trade services of automotive fuel	395	0.35	0.0000
51	Wholesale trade and commission trade, except of motor vehicles and motorcycles	1586	0.95	0.0013
52	Retail trade services, except of motor vehicles and motorcycles; repair services of personal and household goods	395	0.11	0.0000
55	Hotel and restaurant services	45	0.04	0.0000
60.1	Railway transportation services	17	0.00	0.0000
60.2-3	Other land transportation services and transportation services via pipelines	118	0.00	0.0000
61	Water transport services	28	0.04	0.0000
62	Air transport services	10	0.00	0.0000
63	Supporting and auxiliary transport services	211	0.00	0.0000
64	Post and telecommunication services	125	4.76	0.0160
65	Financial intermediation services, except insurance and pension funding services	54	0.39	0.0000
67	Services auxiliary to financial intermediation	21	0.00	0.0000
70	Real estate services	306	0.07	0.0000
71	Renting services of machinery and equipment, without operator and of personal and household goods	71	0.04	0.0000
72	Computer and related services	160	0.01	0.0000
73	Research and development services	43	173.63	0.2093
74	Other business services	1903	2.26	0.0068
75.1-2	Public administration and defence services	20	0.00	0.0000
75.3	Compulsory social security services	3	0.00	0.0000
80	Education services	18	0.00	0.0000
85	Health and social work services	516	0.00	0.0000
90	Sewage and refuse disposal services, sanitation and similar services	78	4.96	0.0000
91	Membership organization services n.e.c.	20	0.00	0.0000
92	Recreational, cultural and sporting services	73	0.15	0.0000
93	Other services	87	0.21	0.0115