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presented by
BENEDIKT RYDZEK
Master in Quantitative Economics, University of Alicante
Diplom Volkswirt, University of Mannheim
born 7 July 1983
citizen of Germany

accepted on the recommendation of
Professor Peter H. Egger, examiner
Professor James R. Markusen, co-examiner

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Abstract

This thesis is a collection of three independent essays in international economics. It analyses the effects of free goods and capital flows on economies. In the first essay (coauthored with Simon Bösenberg and Peter Egger) we formulate a model of economic growth to study the effects of broad capital taxation (of profits, dividends, and capital gains) with internationally mobile capital on macroeconomic outcomes. A framework of exogenous growth permits modeling countries in transition to a country-specific steady state and to discern steady-state and transitory effects of shocks on economic outcomes. The chosen framework is amenable to structural estimation and – given the parsimony in terms of unknown parameters – fits data on 79 countries over the period 1996-2011 extraordinarily well. A quantitative exercise shows that a general capital tax reduction of 10% induces positive effects on output and the capital stock (per unit of effective labor) that are economically significant and are accommodated within time windows of 5 years without much further economic response after that. The effects are strongest for corporate profit tax rates and weaker for dividend and capital gains taxes. From a welfare perspective, reducing capital taxes would be beneficial for some countries (e.g., Germany) but not for others (e.g., the United States).

In the second essay I analyze why countries with a more equal income distribution consume, produce, and trade more manufacturing goods. For this, I develop a model of non-homothetic preferences and structural change. I use a (non-homothetic) Price-Independent Generalized Linear (PIGL) utility function that allows to aggregate individual demand functions and to summarize the within-country inequality in one parameter in the aggregate demand function. The model predicts that for a given GDP
per capita more income equality is associated with a bigger market for manufacturing goods which leads to more concentrated production in countries with higher equality levels. If two countries are similar in terms of equality, increasing equality in either country increases trade between both countries. The model predictions are in line with empirical findings using an augmented gravity equation. Moreover, I estimate the parameters of the model and use these results to calibrate a multi-country model of bilateral trade for 13 OECD countries that fits the data very well.

In the last essay I analyse how trade liberalization affected technological progress and consequently the wage inequality between high skilled and low skilled workers in the United States. Skill-biased technological change and international trade have emerged as alternative explanations for the increasing college wage gap in the US since the 1980s. Most models neglect the effect of international trade on technological progress and hence understate the effects of trade on wage inequality. I develop a model in which bilateral trade increases the wage gap in two trading countries simultaneously, being consistent with the global increase of inequality during the era of trade liberalization. In the model, the wage gap increases due to a disproportional change of wages of high-skilled workers relative to wages of low-skilled workers, which is consistent with empirical findings. The model does not rely (exclusively) on the Stolper-Samuelson theorem, as trade-induced technological change reduces the change in the relative price of high-skill-intensive goods. Lastly, the model matches the trend of unemployment rates of high- and low-skilled workers in the US.
Zusammenfassung


1. Introduction

Decreasing transportation costs and deregulation of international financial markets dramatically increased the flows of goods and capital between countries in the last decades. The world today is more integrated than ever before. Figure 1.1 shows the KOF globalization index and its subindices of economic globalization, actual trade flows and international economic restriction. All these indices increased substantially since the 1970s. Part of the globalization is technology driven by the

![Figure 1.1: KOF Globalization Index. 207 countries, 1970 - 2010. Unweighted averages.](image-url)
Chapter 1. Introduction

decreasing transportation and communication costs. Still governments decide to which extent countries open themselves to the rest of the world. All deregulations and reductions of international tariffs are based on political decisions, which might have significant effects on the development of countries and the well-being of the people living in them. Accordingly, it is important to understand the forces and consequences of free capital and goods flows. Analyzing closed economies omits this important point and this might lead to limited and unrobust results for economic policies.

This thesis consists of three independent essays analyzing the effects of globalization of capital and goods flows. In each of the three essays I present a theoretical model of an open economy and show how the integration of an economy into the world market affects macroeconomic outcomes such as inequality, trade flows or capital accumulation. Furthermore, I calibrate each model to quantify economic effects of interests.

In the first essay of my thesis I analyze the effects of capital taxes for a small open economy within an exogenous growth model on macroeconomic outcomes such as output, capital, investment, output growth, capital growth, consumption, and welfare. Countries responses to changes in capital taxation are very heterogeneous. While lower capital taxes increase output, capital, and consumption in the long run, growth effects occur only in the short run. Moreover, in terms of individual welfare, not all countries gain from a reduction of capital taxation, as the consumption and savings decision is distorted. I argue that the heterogeneous response is due to several reasons. First, countries differ in their initial conditions, i.e., initial taxes, technology, population growth and net investment position of the countries. Second, different taxes on capital such as the corporate profit tax, the dividend tax, and the capital gains tax have different effects on economic outcomes. The strongest effect arises from corporate profit taxation, while dividend and capital gains taxes have smaller effects. In terms of country heterogeneity I use a broad set of 79 countries which differ in their size, tax structure, and technology. Applying the model, I find that in contrast to the well-known finding of Judd (1985) and Chamley (1986) the optimal capital tax can be positive and that decreasing capital taxation might lead to negative welfare effects along the adjustment path, although the model predicts that in the
long run consumption will be higher. The ambiguous welfare effects arise from the fact that consumption drops immediately after the reduction of capital tax rates, as individuals will increase their savings and asset holdings due to higher net returns on investment. In the long-run, the greater asset holdings increase capital, output, and consumption levels. As the short-run consumption has a higher weight in the present discounted utility, the initial drop of consumption might lead to negative net welfare effects of a reduction of capital taxes. Besides level effects the model shows that the convergence to the long run equilibrium levels of capital and consumption is rather fast. I quantify the results by carefully calibrating the model for 79 countries from 1996 to 2011, for which information about corporate profit tax, dividend tax and capital gains tax are available. Within the model I analyze the effects of a reduction of 10% of all three tax instruments in 2008. I find that the level effects are economically significant – output increases on average by 2.56%. Growth effects occur only in the short run, on average the output of the 79 countries would grow by 1.01% for a period of 5 years. After 5 years the growth effects have diminished to almost zero for all countries.

In the second essay, I examine the effects of within- and between-country inequality on trade flows. I analyze why countries with a more equal income distribution consume, produce, and trade more manufacturing goods than others. Most of the classical international trade literature focuses on the effects of international trade on inequality within and between countries. I investigate the opposite: How does the income distribution of a country effects trade patterns? The seminal work of Markusen (1986) and Hunter and Markusen (1988) emphasized the importance of average GDP per capita for trade flows. In this essay I argue that, everything else equal, more equality leads to more trade in manufacturing between two countries. Moreover, the effect is stronger if two countries are initially similar in their income distribution. This squares with the emerging literature on similarity of countries and trade patterns. Most models of international trade rely on Cobb-Douglas or constant-elasticity-of-substitution (CES) utility functions, for which aggregate demand can be easily derived. For this kind of utility the distribution of income is irrelevant and only average GDP matters. In order to introduce income heterogeneity into a trade model I use a non-homothetic Muellbauer (1975) Price-Independent Generalized Linear (PIGL) utility function, from which I
derive aggregate demands as a function of an equality index. The degree of the non-
homotheticity depends on the parameterization of the utility function and can be tested empirically. When I estimate the parameters of the utility function, I find strong evidence for non-homotheticity, indicating that the distribution of income matters for aggregate demand and finally for trade patterns. I solve the model numerically for 13 OECD countries a multi-country model. The model-predicted trade flows match the observed trade flows very well, which makes the model highly suitable for counterfactual analysis.

In the last essay I analyze how trade liberalization affected technological progress and consequently the wage inequality between high-skilled and low-skilled workers in the United States. The classical Heckscher-Ohlin model can explain an increasing wage gap between college-educated workers (high-skilled) and workers with just a high-school diploma (low-skilled), but relies on the change in the relative price along the lines of the Stolper-Samulson theorem. Since the 1980s, when wage inequality started to increase dramatically while the relative price of high-skill-intensive goods to low-skill-intensive goods stayed quite stable. These simultaneous developments contradict the classical Heckscher-Ohlin channel for an increasing wage gap. A common explanation for the increasing wage gap is skill-biased technological change, which became the dominant explanation for the increasing wage gap between high- and low-skilled workers. In this essay, I reconcile both explanations. I argue that trade liberalization can induce skill-biased technological change and hence contributed to the increasing wage gap in the 1980s in the United States without changing the relative price significantly. Furthermore, the unemployment rates for low-skilled workers decreased faster than for skilled workers in the 1980s and 1990s. While trade models such as the one by Moore and Ranjan (2005) predict that unemployment increases after trade liberalization and wages of low-skilled workers decline, I argue that, if trade has an effect on technology, the reverse might be true. I develop a model of endogenous technological change, international trade, and imperfect labor markets to explain the increasing college wage gap and decreasing unemployment rates for both skill groups in the United States in the 1980s. I argue that this is applicable to trade between two similar developed countries that respect intellectual property rights as trade increases the market size for innovations and hence increases investment into research and development.
(R&D). I introduce search frictions in the labor market into the model to obtain the dynamics of the labor market. Higher R&D investments and, in turn, higher technology levels make employment for both skill groups more profitable, but the changes in the employment levels limit the effect on the relative price.

The three chapters follow below.
Bibliography


2. Capital Taxation, Investment, Growth, and Welfare

2.1 Introduction

Whether countries should remove taxes on mobile capital or not is a vividly-debated question. Empirically, corporate profit tax rates have been found to be more or less unambiguously detrimental for GDP growth across countries (see Lee and Gordon, 2005, for evidence in a panel of 70 countries; Arnold et al., 2011, for evidence in the United States) as well as across subnational units (see Ferede and Dahlby, 2012, for evidence across Canadian provinces). Similar effects along those lines have been found for capital gains taxes (see Hungerford, 2010, for evidence regarding the United States) and for dividend taxes in OECD countries (see Dackehag and Hansson, 2012).

Theoretically, the effects of capital taxation depend on the nature of economic growth (exogenous or endogenous), on the effects of capital taxation on other investments than ones in gross fixed capital formation, and on whether the associated tax revenues generate public goods or spillovers (externalities). For instance, in models of exogenous economic growth, where capital and output in units of effective labor stay constant in the steady state and savings only finance the formation of fixed capital, taxes on capital and capital income do not affect economic growth but have detrimental effects on capital stock and output levels (see Judd, 1985; Chamley, 1986). However, if capital taxation leads to investments in intangibles (e.g., through research and development) capital taxation in a Judd-Chamley framework might even raise output (see Aghion
et al., 2013). Clearly, in all models of exogenous economic growth, capital taxation affects growth only in the transition to the new steady state, and then the question is how relatively persistent the growth effects are. In endogenous growth models, capital and output in units of effective labor grow forever. However, even then capital taxation does not need to affect economic growth (see Stokey and Rebelo, 1995), but it will distort economic growth in many such models (see Lucas, 1990; King and Rebelo, 1990; Jones et al., 1993). Stokey and Rebelo (1995) provide a review of the literature of capital taxation with endogenous economic growth. In spite of negative effects on output levels per unit of effective labor emerging from most models of economic growth cum capital taxation, the associated consumer welfare effects do not need to be negative. Russo (2002) finds negative welfare effects along the transition to the new steady state in an exogenous growth model. However, the welfare effects from taxing capital may be positive if tax revenues are used to provide public goods or generate spillovers (see Uhlig and Yanagawa, 1996; Gruener and Heer, 2000; Baier and Glomm, 2001). While most previous theoretical models discussed capital taxation in a relatively narrow definition – through direct taxes on the capital stock or interest payments – the expected effects from dividend and capital gains taxation on investment and transitional growth of output, capital, and consumption are qualitatively similar to those of a direct taxation of capital (see Gourio and Miao, 2011). Recently, Korinek and Stiglitz (2009) show in a life-cycle model that only anticipated changes in dividend taxation distort economic growth.

This essay contributes to this debate along four lines. First, the main contribution is quantitative, estimating behavioral impulse-responses of macroeconomic aggregates to changes in three different broad corporate capital tax instruments across a relatively large set of economies. Second, it does so by formulating a theoretical dynamic model of a small open economy with exogenous growth and internationally mobile capital that features broad capital taxation through three instruments: corporate profit taxation, dividends taxation, and capital gains taxation. A key purpose of this model is its amenability to structural estimation and quantitative analysis with many countries that are repeatedly observed over time. Third, it collects data on the aforementioned capital tax instruments together with macroeconomic variables such as real GDP, capital
2.1. Introduction

stocks, population growth and technological progress for 79 economies and 16 years between 1996 and 2011. Fourth, apart from estimation, it simulates theory-consistent impulse-response functions of changes in broad capital taxation for various economic outcomes, including welfare. The proposed stylized small-open-economy model of exogenous growth with optimal firm-level investment cum broad capital taxation is shown to fit the data extraordinarily well and to result in plausible predictions regarding dividend-payout ratios or Tobin’s $q$. Moreover, while capital taxation tends to reduce output and capital per unit of effective labor, lowering it is shown to benefit some but not all economies, and it does so at remarkably big heterogeneity. The reason is that a tax reduction leads to more investment and leaves less income for consumption in the short-run, while consumption will unambiguously increase in the long-run. Depending on country-specific characteristics and transitional dynamics, discounted utility per unit of effective labor may rise or fall with capital taxation or its abolishment. The latter illustrates the qualitative importance of transition path features when evaluating the welfare implications of changes in capital tax policy.

The essay builds on the framework of Abel (1982) and Barro and Sala-i-Martin (2004) in which firms maximize their present value over the optimal capital stock and investment. In order to determine a firm’s present value under various taxes, we follow Turnovsky and Bianconi (1992) and Turnovsky (2000). Not only in the data but also in the model, capital may be taxed in the form of profits, of dividends, and of capital gains. The latter are assumed to be realized and taxed at the end of every period (see Auerbach, 1991, and Auerbach and Siegel, 2000, for an analysis of deferral, which we abstract from, here). Stokey and Rebelo (1995) and Mendoza et al. (1997) point out that there is only very little impact of capital taxation on long-run growth, so we consider an exogenous growth model with capital adjustment costs as in Sen and Turnovsky (1990) as appropriate and focus on the transitional dynamics of output, capital, consumption and the associated growth rates.
The results point to a stark heterogeneity in the effects on outcome levels per unit of effective labor of a proportional reduction of the three types of capital tax rates (by 10%) across tax instruments as well as across countries. Growth effects occur mainly in the short-run – within five years after a tax change. Although a reduction of any capital tax rate unambiguously increases output, capital, and consumption in the long-run (as long as those tax rates are positive in the outset, welfare might increase or decline. Hence, representative individuals in some countries (e.g., in Austria, Canada, Italy, Switzerland, and the United States) are predicted to loose from a capital tax reduction for the aforementioned reason. However, in other countries (e.g., in Germany, Spain, Luxembourg, Mexico and the United Kingdom) the opposite is true.

The remainder of the essay is organized as follows. In section 2.2 we introduce a stylized small-open-economy model of exogenous growth and broad capital taxation. An appendix derives detailed results for that model. In section 2.3, we confront that model with data on 79 economies and estimate the key parameters. Moreover, we derive the welfare effects for a sub-set of 21 economies. In section 2.4, we utilize the data on the covered countries and the estimated parameters to generate numerical results about the effects of counterfactually changed capital tax rates. Section 2.5 concludes.

2.2 Model

In this section we outline a framework of a small-open-economy and the rest of the world (ROW), where governments use three tax instruments: a dividend tax rate levied on dividends \( \tau_d \), a capital gains tax levied on the change in equity value \( \tau_g \), and a corporate income tax levied on firms' profits \( \tau_p \). For simplicity, we assume all tax rates to be flat. Moreover, we assume source-based taxation under which taxes are applied to all profits, capital income, and capital gains within the borders of the country, regardless of foreign or domestic ownership. For the notation it will be useful to distinguish between a domestic (unstarred) and foreign (starred) location of economic activity and between a domestic (superscript \( h \)) and foreign (superscript \( f \)) ownership of dividends \( D \) in total and \( d \) per equity unit and equity \( E \) in total and \( e \) per capita).
By this convention $e^{*d}$ is the equity owned per domestic individual in the rest of the world and $D^f$ denotes the total dividend payments to foreign individuals from domestic firms. By the above notation, $D = D^d + D^f$ and $E = E^d + E^f$ and $D = dE$ is the total dividend paid to domestic and foreign individuals.

Denote the domestic consumption of final goods per capita at time $t$ as $c(t)$, use $q$ to denote the price per unit of equity, and normalize the price of the final consumption to unity. In general, we define dotted variables as time changes, i.e., $\dot{x} = \frac{\partial x}{\partial t}$. Domestic individuals receive utility from final goods consumption only. They spend their income on final good consumption, $c(t)$, and on new equity at home and abroad, $qe^d$ and $q^*e^{*d}$, respectively. Domestic households receive income from five sources: dividend payments on domestic equity net of dividend taxation, $(1 - \tau_d)d^{d}e^d$, the net-of-tax capital gains of domestic equity, $(1 - \tau_g)\dot{q}e^d$, which we assume to be realized at the end of every period, from labor input $w$, from the repatriation of net-returns from foreign equity $(rq^*e^{*d})$ – with $r$ denoting the exogenous net rate of return on equity held by domestic individuals in the ROW – and lump-sum transfers $f$ from domestically collected aggregated tax revenues, depending on the efficiency of the domestic tax system, $z \in [0, 1]$, where a higher level of $z$ refers to a more efficient tax system.

### 2.2.1 Households

All $L$ individuals in the small economy have identical preferences and receive a present discounted value of utility of

$$U = \int_0^\infty u(c(t)) \exp(- (\rho - n)t) dt,$$

where $u(c(t))$ is the instantaneous utility function depending on the individual consumption of a final good, $c$, with diminishing returns in $c$, $\rho$ is the individual discount factor which we assume such that $\rho \leq r + n$ in order to ensure a non-declining consumption in the steady state. The population (and employment) grows at an exogenous rate $n$. 
Individuals maximize $U$ subject to their individual current budget constraint, for which we suppress time index $t$ since it indexes every variable:

$$c + q^d d + q^* e^* d = (1 - \tau_d) d^d e^d + (1 - \tau_g) q^d q + r q^* e^* d + w + zf. \tag{2.2}$$

Writing the maximization problem for generic period $t$ as a current-value Hamiltonian, we obtain

$$H = u(c(t)) + \mu \exp^{-a t} \left( (1 - \tau_d) d^d e^d + (1 - \tau_g) q^d q + r q^* e^* q + w + zf - c(t) \right), \tag{2.3}$$

where $\mu$ is the present-value lagrange multiplier of wealth and $a$ is the current-value lagrange multiplier of wealth. The resulting first-order conditions (FOCs) are

$$\frac{\partial H}{\partial c} = 0 \quad \rightarrow \quad u_c(c) = a, \tag{2.4}$$

$$\frac{\partial H}{\partial e^d} = (\rho - n) a - \dot{a} \quad \rightarrow \quad (1 - \tau_d) \frac{d^d}{q} + (1 - \tau_g) \frac{\dot{q}}{q} = \rho - n - \frac{\dot{a}}{a} \tag{2.5}$$

and

$$\frac{\partial H}{\partial e^* d} = (\rho - n) a - \dot{a} \quad \rightarrow \quad r = \rho - n - \frac{\dot{a}}{a}. \tag{2.6}$$

In equation (2.5) we assume, as in Turnovsky and Bianconi (1992), that the individuals take the dividend yields on their equity as given, which allows us to express the first-order condition in terms of dividend yield, $\frac{d^d}{q}$, and the growth rate of the equity value $\frac{\dot{q}}{q}$. Equation (2.6) is the long-run (steady-state) arbitrage condition. In equilibrium, the rate of return on investment in the domestic country, on the left-hand side of equation (2.5), has to match the net rate of return on investment in the rest of the world, $r$. 


2.2. Model

2.2.2 Representative firm

In a generic period $t$ whose index we suppress, the representative firm in a country produces output $Y$ with a Cobb-Douglas production function:

$$Y = F(A, K, L) = K^\alpha (AL)^{1-\alpha}, \quad (2.7)$$

where $L$ is the total labor employed, $K$ is the capital used for production, $A$ is the labor-augmenting technology level, and $\alpha$ is the constant expenditure share on capital in total costs. Labor is immobile and supplied inelastically. Technology grows at the exogenous rate $x$. We may write the production function in intensive form (per unit of effective labor), by dividing it by $AL$:

$$\hat{y} = f(\hat{k}) = \frac{F(A, K, L)}{AL} = \hat{k}^\alpha, \quad (2.8)$$

where $k$ is the capital per worker and $\hat{k}$ and $\hat{y}$ are the capital used and output generated per unit of effective labor, respectively. For further use, we will define $\hat{x} \equiv x/AL$ for any generic variable $x$. The firm’s gross profits, $\Pi$, are

$$\Pi = F(A, K, L) - Lw - I\psi, \quad (2.9)$$

where $\psi = g \left( \frac{I}{K} \right)$ gives the costs of adjusting the physical capital stock and is assumed to be homogeneous of degree one in $\left( \frac{I}{K} \right)$. Furthermore, we assume that the labor market is competitive whereby the firm pays the marginal product of labor as the wage:

$$w = F_L(A, K, L). \quad (2.10)$$

Net of the corporate profit tax rate, $\tau_p$, profits are either paid as dividends, $D$, or retained in the firm, $R$, so that

$$(1 - \tau_p)\Pi = D + R. \quad (2.11)$$

Total dividend payments are paid either to domestic individuals, $D^d$, or to foreign ones, $D^f$, according to their equity, $E^d$ and $E^f$, respectively.
The total value of equity in the economy is $V = qE$. The change in the total value of equity in the domestic economy equals the change in the value of equity plus the change in equity:

$$\frac{\partial V}{\partial t} = \dot{V} = \dot{q}E + q \dot{E}. \quad (2.12)$$

Total investment is given by has to be equal to retained earnings, $R$, plus the change in equity, $q \dot{E}$:

$$I = \dot{K} + \delta K = q \dot{E} + R. \quad (2.13)$$

Capital is assumed to depreciate at a constant and exogenous rate $\delta$. Combining equations (2.11) and (2.12) with equation (2.13), we obtain a first-order differential equation for the change in total value of equity:

$$\dot{V} = \frac{r}{1 - \tau_g} V - \left(\frac{\tau_g - \tau_d}{1 - \tau_g}\right) D - \gamma, \quad (2.14)$$

where $\gamma \equiv (1 - \tau_p)\Pi - I$. See the Appendix A for more details.

Assuming that the firm distributes a share $\phi \in [0, 1]$ as dividends and retains $1 - \phi$ of the profits, dividend payments are defined as:\(^1\)

$$D = \phi(1 - \tau_p)\Pi. \quad (2.15)$$

Substituting this in equation (2.14) yields,

$$\dot{V} = \frac{r}{1 - \tau_g} V - (1 - \tau) \left(F(A, K, L) - wL - I\psi\right) + I, \quad (2.16)$$

where we define $1 - \tau \equiv \frac{(\phi(1 - \tau_d) + (1 - \phi)(1 - \tau_g))(1 - \tau_p)}{1 - \tau_g}$.

\(^1\)As shown in equation (2.13), investment is financed with retained earnings and new equity while the firm takes the dividend payout ratio, $\phi$, as given. Thus, dividend taxation may lead to changes in investment and the model is closer related to the "old view" as discussed in Auerbach (1979) and Keuschnigg (2005).
2.2. Model

We may now integrate equation (2.16) as in Brock and Turnovsky (1981) and Turnovsky and Bianconi (1992) to obtain the present value of the firm:

\[
V(0) = \int_{0}^{\infty} ((1 - \tau)(F(A, K, L) - wL - I\psi) - I) \exp \left( - \int_{0}^{t} \frac{r(s)}{1 - \tau_g} ds \right) dt.
\]  

(2.17)

The firm maximizes its present value, \( V(0) \), over \( I \), subject to \( I = \dot{K} - \delta K \) and a given \( K(0) > 0 \). Taking the net rate of return in the rest of the world, \( r \), and all capital taxes as constant over time from the firm’s perspective gives the following current-value Hamiltonian:

\[
J = \exp \left( \frac{r}{1 - \tau_g} \right) ((1 - \tau)(F(A, K, L) - wL - I\psi) - I + \eta(I - \delta K)),
\]  

(2.18)

where \( \eta \) is the current-value lagrange multiplier of the constraint, the shadow price of capital, which is also known as Tobin’s \( q \). For convenience and in line with a large literature (see, e.g., Caballero, 1999; Altig et al., 2001; Hall, 2004), we assume that the function of capital adjustment cost is \( \psi = \frac{b L}{K} = \frac{b \dot{k}}{2k} \).

The corresponding FOCs are

\[
\frac{\partial J}{\partial I} = 0 \rightarrow \frac{\eta - 1}{b(1 - \tau)} = \frac{\dot{i}}{k},
\]  

(2.19)

and

\[
\frac{\partial J}{\partial K} = \eta \left( \frac{r}{1 - \tau_g} \right) - \dot{\eta} \rightarrow \dot{\eta} = \left( \frac{r}{1 - \tau_g} + \delta \right) \eta - (1 - \tau) \left( f_{\hat{k}}(\hat{k}) + \frac{b}{2} \left( \frac{\dot{k}}{\hat{k}} \right)^2 \right),
\]  

(2.20)

where we use the homotheticity of the production function and the capital adjustment cost function to write all expressions in terms of units of effective labor.

2.2.3 Steady-state equilibrium

Using \( \dot{k} = \dot{i} - (x + n + \delta)\hat{k} \) in equation (2.19), we may express the change of \( \hat{k} \) as

\[
\dot{\hat{k}} = \left( \frac{\eta - 1}{b(1 - \tau)} - (x + n + \delta) \right) \hat{k}.
\]  

(2.21)
Since we have $\dot{\hat{k}} = 0$ in the steady state, we can solve the above equation for the steady-state value, $\bar{\eta}$:

$$\bar{\eta} = 1 + b(x + n + \delta)(1 - \tau),$$  \hspace{1cm} (2.22)

which is independent of $\hat{k}$ and represents a horizontal locus in a phase diagram with $\hat{k}$ on the abscissa. Similarly, we may re-write equation (2.20) and substitute equation (2.19) to obtain

$$\dot{\eta} = \left( \frac{r}{1 - \tau_g} + \delta \right) \eta - (1 - \tau) f_\hat{k}(\hat{k}) - \frac{(\eta - 1)^2}{2b(1 - \tau)}.$$  \hspace{1cm} (2.23)

The two differential equations (2.21) and (2.23) may now be used to construct the phase diagram of the dynamic system in Figure 2.1 in $\hat{k}$-$\eta$-space. The $\dot{\hat{k}} = 0$ locus represents equation (2.21), whereas the $\dot{\eta} = 0$ locus represents equation (2.23). The latter is downward sloping near the steady state if $\frac{r}{1 - \tau_g} > x + n$. To show this, we use that $\dot{\eta} = 0$ and $\bar{\eta}$ from equation (2.22) in equation (2.23) and apply the implicit function theorem to obtain $\frac{\partial \eta}{\partial \hat{k}} = -\frac{(1 - \tau)f_{\eta}(\hat{k})}{\dot{\eta} / \dot{\hat{k}} - (x + n)}$. As $f_{\eta}(\hat{k}) < 0$, we have $\frac{\partial \eta}{\partial \hat{k}} < 0$ if and only if $\frac{r}{1 - \tau_g} > x + n$. Hence, the $\dot{\eta} = 0$ locus is downward sloping around the steady state.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{phase_diagram.png}
\caption{Phase diagramm of $\hat{k}$ and $\eta$. Saddle path stable.}
\end{figure}
Using that in the steady state $\dot{\eta} = 0$ and substituting equation (2.22) yields the steady-state value of capital per unit of effective labor, $\tilde{k}$, as:

$$
\tilde{k} = \left( \frac{1}{\alpha} \left( \frac{r}{1 - \tau_g} + \delta \right) \frac{1}{1 - \tau} + (x + n + \delta) b \left( \frac{r}{1 - \tau_g} + \frac{\delta - x - n}{2} \right) \right)^{\frac{1}{\alpha - 1}}. \tag{2.24}
$$

It is straightforward to show that the optimal capital stock decreases in $r$, $\tau_p$ and $\tau_d$. For a sufficiently big capital adjustment cost parameter, $b$, the optimal capital stock as well decreases in $\tau_g$. \footnote{\[ b > (1 - \tau_g)^2 \frac{\delta - r (1 - \phi)}{(x + n + \delta) r (1 - \tau_g)(1 - \tau_d)(1 - \tau_p) + (x + n) (1 - \tau_g) + (x + \delta)(1 - \tau_p) + x (1 - \tau_d)} \] implies that $\frac{\partial \tilde{k}}{\partial \tau_g} < 0$.}

### 2.2.4 Dynamics

Linearizing the two dynamic equations (2.21) and (2.23) around their steady states yields

$$
\begin{pmatrix}
\dot{\tilde{k}} \\
\dot{\tilde{\eta}}
\end{pmatrix} = \begin{bmatrix}
0 & \frac{\dot{\tilde{k}}}{b(1 - \tau)} \\
-(1 - \tau) f_{\tilde{k}\tilde{k}}(\tilde{k}) & \frac{x}{1 - \tau_g} + \delta - \left( \frac{\tilde{\eta} - 1}{b(1 - \tau)} \right)
\end{bmatrix} \times \begin{bmatrix}
(\tilde{k} - \tilde{k}) \\
(\tilde{\eta} - \tilde{\eta})
\end{bmatrix}, \tag{2.25}
$$

after substituting $\tilde{\eta}$ from equation (2.22) and $\tilde{k}$ from equation (2.24), the two eigenvalues, $\lambda_{1,2}$, are

$$
\lambda_{1,2} = \frac{r}{1 - \tau_g} - \frac{(x + n)}{2} \pm \left( \left( \frac{r}{1 - \tau_g} - \frac{(x + n)}{2} \right)^2 + \frac{(1 - \alpha)}{b} \left( \left( \frac{r}{1 - \tau_g} + \delta \right) \frac{1}{1 - \tau} + (x + n + \delta) b \left( \frac{r}{1 - \tau_g} + \frac{\delta - x - n}{2} \right) \right) \right)^{\frac{1}{2}}. \tag{2.26}
$$

Notice that the root is always greater than unity as $f_{kk}(\tilde{k}) < 0$ and, hence, $\lambda_1$ and $\lambda_2$ will have different signs, as already indicated by the saddle path stability in the phase diagram above.
Starting from initial values \( \hat{k}(0) \) and \( \eta(0) \) the paths of \( \hat{k}(t) \) and \( \eta(t) \) for period \( t \) are given by

\[
\begin{align*}
\hat{k}(t) &= \hat{k} + (\hat{k}(0) - \hat{k})\exp(\lambda t), \\
\eta(t) &= \tilde{\eta} + (\eta(0) - \tilde{\eta})\exp(\lambda t),
\end{align*}
\]

(2.27) (2.28)

where \( \lambda \) corresponds to the stable (negative) eigenvalue.

### 2.2.5 Dividend payout ratio

So far we have only considered investments financed either by new equity or in form of retained earnings and refrained from debt finance. Moreover, we have taken the dividend payout ratio as given and not as a choice variable of the firm. In this section, we derive the dividend payout ratio, \( \phi \), as an endogenous variable in the model. In the optimum, the firm sets the dividend payout ratio such that it equalizes the costs of capital under investment financed by new equity and by retained earnings.

Furthermore, for a certain parameterization of the gross interest rate in the domestic country, \( \bar{r} \), the cost of financing an investment by retained earnings, new equity, or debt are equivalent. This equivalence allows us to consider only retained earnings and new equity and to omit debt finance in our analysis. To show these results, we proceed as follows. First, we calculate the capital costs of financing an investment by retained earnings or new equity. Second, we compute the dividend payout ratio, that makes the investor indifferent between these two forms of finance. Third, we derive the capital costs of debt finance and show under which condition for the gross interest rate, \( \bar{r} \), these costs are identical to the capital costs of retained earnings and new equity.

**Retained earnings:**

Assume that the firm invests one unit of potential dividend payments into capital, thereby reducing actual dividend payments to the individual owners. An individual owner of the firm will lose \( \frac{1 - \tau_d}{1 - \tau_g} \) units of dividend payments after taxes in period \( t \) as shown by Devereux and Griffith (1998). The firm transforms the investment into capital, which gives \( \kappa = \left( 1 - \frac{b}{2R} \right) \) units of additional capital. We denote the profits created by
2.2. Model

this additional capital as \( \pi^{RE} \) as they are created by retained earnings. In the next period \((t + 1)\) the firm de-invests the capital, which increases profits by \( \left(1 - \frac{b \kappa (1 - \delta)}{2(K + \kappa (1 - \delta))}\right) \) units. Finally, we assume that the individual investor only compares dividend payments in the two periods and does not consider the effect of this investment strategy on the equity value.\(^3\) The net dividend payments from the profits would be \( \phi(1 - \tau_p)(1 - \tau_d) \).

The return of this investment strategy is

\[
R^{RE} = \frac{1 - \tau_d}{1 - \tau_g} + \frac{\left(\pi^{RE} + \left(1 - \frac{b \kappa (1 - \delta)}{2(K + \kappa (1 - \delta))}\right)\right)}{\frac{1 + r - \tau_g}{1 - \tau_g}} \phi(1 - \tau_p)(1 - \tau_d),
\]

where \( \frac{1 + r - \tau_g}{1 - \tau_g} \) is the discount rate for the case of retained earnings, see Devereux and Griffith (1998). We set \( R^{RE} = 0 \) and solve this equation for \( \pi^{RE} \), which is the cost of capital:

\[
\pi^{RE} = \frac{(1 + r - \tau_g)}{\phi(1 - \tau_p)} - \left(1 - \frac{b \kappa (1 - \delta)}{2(K + \kappa (1 - \delta))}\right).
\]

**New equity:**

In contrast to the first case with retained earnings, the firm here issues new equity worth one unit, which is again invested into capital. All profits from this investment,

\(^3\)We do not consider changes in the equity value \( \dot{q} \) as they have only a minor impact on the margin if the value of the firm is sufficiently high. The intuition for this small change in equity value arises from the fact that the firm de-invests the capital stock it had created in the first period and hence (partly), reverses the initial effect of a higher investment on the equity value. If the value of the firm, \( V \), is sufficiently high, a small change in the flow of profits will lead to only small changes in the value of the firm and, hence, in the equity value. To see this more formally, combine equations (2.5) and (2.6) and solve for the change in equity value, \( \dot{q} \):

\[
\dot{q} = \frac{r}{1 - \tau_g} q - \frac{1 - \tau_d}{1 - \tau_g} V.
\]

Given the value of the firm, \( V \), and the price of equity, \( q \), reducing dividends by one unit increases the value of equity by \( \frac{1 - \tau_d}{1 - \tau_g} \) units, as it increases the capital stock and, hence, future profits. In the next period, the reverse effect takes place, which decreases the value by the same amount. The change is smaller the bigger is the value of the firm. The net effect of changes in the equity value is given by

\[
\frac{1 - \tau_d}{1 - \tau_g} V - \frac{1 - \tau_d}{1 + r - \tau_g} V = \frac{1 - \tau_d}{1 - \tau_g} V \left(\frac{r - \tau_g}{1 + r - \tau_g}\right),
\]

which is decreasing in \( V \). Thus, for high values of \( V \) the net effect is rather small and we omit it in the analysis to simplify notation.
\( \pi^{NE} + \left(1 - \frac{b \kappa (1 - \delta)}{2(K + \kappa(1 - \delta))}\right) \), are paid as dividends to the investor in the next period. This means that profits from this investment are taxed at \((1 - \tau_p)(1 - \tau_d)\). The investor could gain a net return of \(1 - r\) if she invested in the rest of the world, which gives the discount factor. The return on investment using new equity, \(R^{NE}\), is given as

\[
R^{NE} = -1 + \left(\frac{\pi^{NE} + \left(1 - \frac{b \kappa (1 - \delta)}{2(K + \kappa(1 - \delta))}\right)}{1 + r}\right)(1 - \tau_p)(1 - \tau_d).
\]

(2.31)

We solve for the cost of capital under finance with new equity, \(\pi^{NE}\), by setting \(R^{NE} = 0\):

\[
\pi^{NE} = \frac{1 + r}{(1 - \tau_p)(1 - \tau_d)} - \left(1 - \frac{b \kappa (1 - \delta)}{2(K + \kappa(1 - \delta))}\right) 
\]

(2.32)

Dividend payout ratio:

We determine the endogenous dividend payout ratio, \(\phi\), that makes the firm indifferent between the two investment strategies by equalizing the capital costs of investment for both strategies:

\[
\pi^{NE} = \pi^{RE},
\]

(2.33)

which leads to

\[
\phi = \frac{(1 + r - \tau_g)(1 - \tau_d)}{1 + r}.
\]

(2.34)

Debt:

In the case of debt finance the firm borrows one unit in \(t\) and repays \((1 + \bar{r})\) units in \((t + 1)\). We denote the profits from this investment by \(\pi^{D}\) and the return by \(R^{D}\). For the individual investor, the gross costs reduce the profits, \(\pi^{D}\), in period \((t + 1)\) and hence implicitly the dividends and capital gains in this period:

\[
R^{D} = \left(\pi^{D} + \left(1 - \frac{b \kappa (1 - \delta)}{2(K + \kappa(1 - \delta))}\right)\right)(1 - \tau_p) - (1 + \bar{r}).
\]

(2.35)
Again we solve for $\pi^D$ using $R^D = 0$:

$$
\pi^D = \frac{1 + \bar{r}}{1 - \tau_p} - \left(1 - \frac{b\kappa(1 - \delta)}{2(K + \kappa(1 - \delta))}\right).
$$

(2.36)

For the firm to be indifferent between financing by debt or retained earnings, the capital cost have to be equal, $\pi^D = \pi^{RE}$:

$$
\frac{1 + \bar{r}}{1 - \tau_p} = \frac{(1 + r - \tau_g)}{\phi(1 - \tau_p)}.
$$

(2.37)

We solve this expression for $\phi$:

$$
\phi = \frac{(1 + r - \tau_g)}{(1 + \bar{r})}.
$$

(2.38)

The dividend payout ratio in equations (2.34) and (2.38) is the same if

$$
\bar{r} = \frac{1 + r}{1 - \tau_d} - 1.
$$

(2.39)

### 2.2.6 Consumption

We may use the individual budget constraint to determine the change of total asset holdings per unit of effective labor, $\dot{\nu}$, as a function of the level of asset holdings per unit of effective labor, $\dot{\nu}$, as well as wages, transfers, and consumption per efficiency unit, $\{\dot{w}, \dot{f}, \dot{c}\}$, respectively:

$$
\dot{\nu} = \dot{w} + (r - x)\dot{\nu} + z\dot{f} - \dot{c}.
$$

(2.40)

We linearize equation (2.40) around its steady state, using that the wage $\dot{w}$ and transfers $\dot{f}$ are a function of $\dot{k}$ and that $\dot{c}$ is a function of the marginal utility of wealth, $a$. Moreover, we linearize equation (2.5) and solve the differential equation to express $a$ as a function of $\dot{k}$. Additionally, we assume that the markets are forward-looking so that $\eta$ immediately adjusts to the new steady state. Then, we can express $\dot{\nu}$ as a function of $\dot{k}(0), \dot{k}, a(0), \dot{a}, \dot{\nu}(0)$, and $\dot{\nu}$. Last, note that with log-utility and $\rho = n + x$, $\dot{c}$ is constant.
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in the steady state and, hence, $\dot{a}$ is constant. Based on this catalogue of assumptions, we may solve (implicitly) for the steady-state level of consumption, $\bar{c}$. See Appendix C for the detailed derivations.

2.3 Empirical analysis

2.3.1 Data

We combine data from the PennWorld Tables (Version 8.0), Feenstra et al. (2013), with comprehensive data for corporate profit tax and capital taxes for 79 countries between 1996 and 2011 which were collected by the authors. For the corporate profit tax rate, $\tau_p(t)$, we use the maximum corporate profit tax rate in a country and year. The capital gains tax rate, $\tau_g(t)$, is the maximum tax rate at the national level on corporate capital gains in a country of residence. The dividend tax rate, $\tau_d(t)$, is defined as the maximum tax rate at the national level for distributed dividends in a country at time $t$. In Appendix D we provide data sources for each tax instrument and describe how the heterogeneity in the tax systems across countries is acknowledged when calculating the tax rates. Table 2.1 provides summary statistics for the three tax instruments across all countries

<table>
<thead>
<tr>
<th>Variable</th>
<th># Obs.</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau_p$</td>
<td>1264</td>
<td>0.287</td>
<td>9.01</td>
<td>0</td>
<td>57</td>
</tr>
<tr>
<td>$\tau_g$</td>
<td>1264</td>
<td>0.228</td>
<td>13.03</td>
<td>0</td>
<td>55</td>
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<tr>
<td>$\tau_d$</td>
<td>1264</td>
<td>0.647</td>
<td>9.40</td>
<td>0</td>
<td>40</td>
</tr>
</tbody>
</table>

Table 2.1: *Capital taxes. Summary statistics.*

Corporate profit tax rate, $\tau_p$, capital gains tax rate, $\tau_g$ and dividend tax rate, $\tau_d$, 1996 - 2011. 79 countries. Various sources.

and years in the data. Figures 2.2 to 2.4 show the distribution of the aforementioned tax rates for each year in the data, using whisker-plots. The area around the median (a horizontal bar) indicated by a box refers to the interquartile range (IQR), whereas the extended lines, the whiskers, indicate values within a maximum of 1.5 times the IQR. The corporate profit tax rates in Figure 2.2 show a relatively high degree of variability over time, even at the median. The median capital gains tax rate in Figure 2.3
2.3. Empirical analysis

decreases smoothly and modestly over the sample period. The distribution of dividend
tax rates in Figure 2.4 is skewed towards zero with the median being constant at zero
throughout the sample period. Other variables such as real GDP, total employment, the
capital share of production and total real capital stock are taken from the PennWorld
Tables. The key variable of the model is the capital stock per unit of effective labor. We
take the total capital stock for each country and year directly from the PennWorld Tables
and divide it by the number of workers employed in each country and year. In order to
obtain the labor technology parameter, we solve the Cobb-Douglas production function
for $A_j(t)$ for each country $j$ and year $t$:

$$A_j(t) = \left( \frac{y_j(t)}{k_j(t)^{\alpha_j}} \right)^{\frac{1}{1-\alpha_j}},$$

(2.41)

where $y_j(t)$ is the real GDP per worker in constant 2005 USD in country $j$ and year
$t$, $k_j(t)$ is the capital stock per worker in constant 2005 USD, and $\alpha_j$ is the average
capital share of production in each country between 1996 and 2012. For each country
separately we use a Hodrick-Prescott filter with a smoothing parameter of 6.25 for
annual data to detrend the technology parameter as it varies strongly with the business
cycle. We obtain the capital stock per unit of effective labor by dividing the total real
capital stock, $K_j(t)$, by the number of workers employed times the labor technology
parameter, $A_j(t)\bar{L}_j(t)$, for each country and year. Moreover, we utilize the obtained
$A_j(t)$ to compute the average growth rate of $A_j(t)$ for each country from 1996 to 2012,
$x_j$. 
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Figure 2.2: Corporate profit tax. 79 countries, 1996 - 2011

As Bond et al. (2003) we set one common depreciation rate $\delta$ equal to 8% for all countries and years.\(^4\) We take the net rate of return from the MSCI Global Equity Index, which considers approximately 99% of each market’s free-float-adjusted market capitalization. The composite net rate of return is around 4.19% per year across all countries.\(^5\) The MSCI Index includes emerging and developing countries some of which, despite of the recession, had high returns on investment throughout the sample period, which may explain why the net rate of return is higher than the typically assumed interest rate of 3% for the United States.

\(^4\)Mankiw et al. (1992) note that depreciation rates vary greatly between countries. For the United States Feenstra et al. (2013) use a depreciation rate of about 6%. Schündeln (2013) estimates depreciation rates for developing countries between 10% and 14%. The parameterization of Bond et al. (2003) seems to be a good balance, as our sample includes relatively more developed countries than developing countries. Still the results do not change qualitatively when using slightly higher or lower depreciation rates.

\(^5\)We thank Credit Swiss for providing us with the data for the MSCI Global Equity Index.
We excluded observations that violate the necessary and sufficient condition for saddle path stability, where the rate of technological progress and population growth are higher than the rate of return in the rest of the world, \( r/(1 - \tau_g) < x + n \). Furthermore, we use the bacon procedure given by Weber (2010) to detect multi-dimensional outliers using a p-value of 30%. Table 2.2 reports the summary statistics for the aforementioned variables across all countries and years after adjusting the data as described.
Section 2. Capital Taxation, Investment, Growth, and Welfare

For illustrative purposes we calculate the mean dividend payout ratio and compare it to the dividend payout ratio we observe for a subset of 70 countries in our sample. We take the mean tax rates and the (net) rate of return in the rest of the world to calculate the dividend payout ratio, \( \phi \), using equation (2.34) that makes firms indifferent between financing an investment with retained earnings or new equity.

\[
\frac{(1 + 0.041 - 0.2279)(1 - 0.0647)}{1 + 0.041} = 0.731,
\]

which is reasonably close to the dividend payout ratio of 0.612 we observe for the subset of 70 countries in our analysis.

Using the same numerical example as above from equation (2.39) we obtain a gross interest rate in the domestic country of \( \bar{r} = \frac{1 + 0.041}{1 - 0.0647} - 1 = 0.113 \). It follows that an

---

Figure 2.4: Dividend tax. 79 countries, 1996 - 2011

---

6The data for the observed dividend payout ratio is described in more detail in the Appendix D.
2.3. Empirical analysis

Table 2.2: Variables. Summary statistics

<table>
<thead>
<tr>
<th>Variable</th>
<th># Obs.</th>
<th>Mean</th>
<th>Std. Dev.</th>
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<th>Max</th>
</tr>
</thead>
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<td>Basic variables</td>
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<td></td>
<td></td>
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<td>Real GDP in mn. USD (Y)</td>
<td>1264</td>
<td>502566</td>
<td>1426616</td>
<td>1197</td>
<td>1.32E+07</td>
</tr>
<tr>
<td>Real GDP per worker in USD (y)</td>
<td>1264</td>
<td>38008</td>
<td>26488</td>
<td>2603</td>
<td>118168</td>
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<td>Employment in mn. (L)</td>
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<td>12.29957</td>
<td>22.42</td>
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<tr>
<td>Real capital in mn. USD (K)</td>
<td>1264</td>
<td>1607431</td>
<td>4528786</td>
<td>4198</td>
<td>4.09E+07</td>
</tr>
<tr>
<td>Real capital per worker in USD (k)</td>
<td>1264</td>
<td>114462</td>
<td>82683</td>
<td>1246</td>
<td>328435</td>
</tr>
<tr>
<td>Trend labor tech. (.A)</td>
<td>1264</td>
<td>16683</td>
<td>14988</td>
<td>350</td>
<td>69955</td>
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<tr>
<td>Variables used in estimation</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real capital per labor eff. unit (k)</td>
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<td>12.91</td>
<td>17.68</td>
<td>0.03</td>
<td>174.14</td>
</tr>
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<td>Capital share in % (α)</td>
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<td>11.05</td>
<td>24.64</td>
<td>77.97</td>
</tr>
<tr>
<td>Net rate of return ROW in % (r)</td>
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<td>0</td>
<td>4.19</td>
<td>4.19</td>
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<tr>
<td>Depreciation rate in % (δ)</td>
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<td>0</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Trend labor tech. growth in % (x)</td>
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<td>0.72</td>
<td>2.21</td>
<td>-9.87</td>
<td>5.98</td>
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<tr>
<td>Employment growth rate in % (n)</td>
<td>1264</td>
<td>1.72</td>
<td>1.16</td>
<td>-1.34</td>
<td>4.49</td>
</tr>
</tbody>
</table>

All real variables are constant 2005 USD. 79 countries, 1996 - 2011.
Source: PennWorld Tables Version 8.0. Notice that while x and n are calculated as annual changes above, we use country-specific time averages across all years for those two parameters.

individual investor is indifferent between new equity and retained earnings finance given the endogenously determined dividend payout parameter. Furthermore, the firm is indifferent between debt, retained earnings and new equity finance given the dividend payout ratio, if the gross interest rate is given by equation (2.39).

To determine consumption, we need the total asset holdings of domestic individuals. We use the net international investment position, NIIP, in percent of GDP as published by the International Monetary Fund (2013) for 21 countries in the year 2008. We calculate the asset holdings per worker as \( ν = k + NIIPy \) for 2008. Appendix E provides the list of countries for which NIIP data are available together with the corresponding NIIP values for 2008.
2.3.2 Estimation

General outline:
In this section, we focus on determining the convergence parameter, $\lambda$, which can be calculated from equation (2.26) based on an estimation of the capital adjustment costs parameter $b$. The higher is $|\lambda|$ the faster is the convergence to the new steady state after a change in tax policy. A value of $\lambda = 0$ implies an absence of convergence.

We may check the plausibility of the regression results in terms of Tobin’s $q$. Based on equation (2.22) and measured variables in conjunction with model estimates, we may compute Tobin’s $q$. While Blanchard et al. (1993) report very low $q$-ratios below 1.8 for the 1980s, research based on more recent data such as Hall (2001) and Laitner and Stolyarov (2003) report values of 3 (based on the ratio of market value to reproduction cost of plant and equipment) and of 2.06, respectively, each of them for data of the year 2000. In the interest of simplifying the notation, it will be useful to define $\theta_j(t) \equiv r_j - \tau_{g,j}(t)$, $\sigma_j \equiv x_j + n_j$, and $1 - \tau_j \equiv \frac{\phi(1 - \tau_{g,j}(t))}{1 - \tau_{g,j}(t)}$ for later use. For all models in levels we will assume an error components structure of $\nu_j + \omega_j(t + 1)$, where $\nu_j$ is time-invariant and $\omega_j(t + 1)$ is not, and $E[\nu_j \omega_j(t + 1)] = 0$. For all models in first differences we will assume an error term of $\Delta \omega_j(t + 1)$, where $\Delta$ denotes the (first-)differencing operator. Since all of the models will turn out to be non-linear in the parameters of interest, we will generally rely on nonlinear least-squares estimation of dynamic models.

**Estimating $b$ on the basis of estimates from the steady-state equation in levels only:**

Using the definitions of $\theta_j(t)$ and $\sigma_j$, we may rewrite the steady-state equation in (2.24) as

$$\tilde{k}_j(t) = \left( \frac{1}{\alpha_j} \left( \frac{\theta_j(t) + \delta}{1 - \tau_j(t)} + (\sigma_j + \delta)b \left( \frac{\theta_j(t) + \delta - \sigma_j}{2} \right) \right) \right)^{\frac{1}{1-\alpha_j}}.$$  

We will refer to model estimates based on this equation with an error components structure $\nu_j + \omega_j(t + 1)$ as Model (1).

---

7We generally use the delta method on the respective equation determining $\lambda$ to derive its standard error.
2.3. Empirical analysis

Estimating $b$ on the basis of estimates of the convergence equation in levels:

$$\hat{k}_j(t + 1) = (1 - \exp(\lambda_j(t)))\tilde{k}_j(t) + \exp(\lambda_j(t - 1))\hat{k}_j(t - 1) + v_j + \omega_j(t + 1), \quad (2.44)$$

where $\tilde{k}_j(t)$ on the right-hand side of (2.44) is replaced by the expression in (2.43) and $\lambda_j(t)$ is replaced by

$$\lambda_j(t) = \frac{\theta_j(t) - \sigma_j}{2} - \left(\left(\frac{\theta_j(t) - \sigma_j}{2}\right)^2 + \frac{1 - \alpha_j}{b} \left(\theta_j(t) + \hat{\delta} \left(\theta_j(t) + \sigma_j + \hat{\delta}\right)\right)\right)^{\frac{1}{2}}. \quad (2.45)$$

We will refer to model estimates based on equation (2.44) with an error components structure $v_j + \omega_j(t + 1)$ as Model (2).

Estimating $b$ on the basis of estimates of the first-differenced convergence equation:

This approach utilizes the model in (2.44) in first differences:

$$\Delta \hat{k}_j(t + 1) = \Delta(1 - \exp(\lambda_j(t)))\tilde{k}_j(t) + \Delta \exp(\lambda_j(t))\hat{k}_j(t) + \Delta \omega_j(t + 1) \quad (2.46)$$

where $\tilde{k}_j(t)$ and $\lambda_j(t)$ are defined in (2.43) and (2.45), respectively. We will refer to model estimates based on this equation with an error term $\Delta \omega_j(t + 1)$ as Model (3).

Estimating $b$ on the basis of estimates of the first-differenced convergence equation with a control function:

This approach utilizes the same model as in (2.46) except for an additive control function $\epsilon_j(t)$:
\[ \Delta \hat{k}_j(t + 1) = \Delta(1 - \exp(\lambda_j(t)))\hat{k}_j(t) + \Delta \exp(\lambda_j(t))\hat{k}_j(t) + \varsigma \Delta \epsilon_j(t) + \Delta \omega_j(t + 1), \quad (2.47) \]

where \( \epsilon_j(t) \) is the residual of the regression.

\[ \Delta \hat{k}_j(t) = \sum_{s=0}^{t-2} \beta(t - 2 - s)\hat{k}_j(t - 2 - s) + X_j(t - 2 - s)\gamma + \epsilon_j(t), \quad (2.48) \]

where the vector \( X_j(t - 2 - s) \) includes all independent variables of the second stage, and \( \gamma \) is an unknown, conformable parameter vector. We will refer to model estimates based on (2.47) with an error term \( \Delta \omega_j(t + 1) \) and endogenously determined \( \phi \) as Model (4). If observed dividend payout ratios are used in the estimation, we will refer to it as Model (4a). If \( \phi \) is an estimated parameter, we will dub this Model (4b).

**Summary of regression results:**

Table 2.3 presents the estimation results for Models (1)-(4b). Clearly, in view of the literature on Tobin’s \( q \) and, somewhat less so, on \( \lambda \), the result of Model (1) seems implausible. In terms of explanatory power and our priors regarding Tobin’s \( q \), the results of the other models look much better. While Model (2) has the highest explanatory power, the estimated capital adjustment costs, \( b \), and Tobin’s \( q \) seem relatively low compared to the common literature. Hence, the two models which are based on data in levels have problems.

This is not the case for the differenced models. In Model (3), we use differenced data, but ignore lagged differences of capital stocks per unit of effective labor on the right-hand side which may induce an endogeneity problem. However, that problem should be relatively small due to the length of the time series (16 years). Model (4) appears to match key moments in the data and the literature best. In that model, Tobin’s \( q \) is also quite close to what had been found by others in the 2000s. All estimates of \( \lambda \) are significantly negative, which ensures saddle path stability and convergence. Finally, the difference in \( \lambda \) between Models (3) and (4) is very small and never statistically significant, which adds confidence in the estimates.
Lastly, $\lambda$ is in the range of what Russo (2002) finds computing numerically the speed of convergence between 0.384 and 0.474 after changes in the corporate profit tax in a linearized Ramsey model using a standard parameterization as Barro and Sala-i-Martin (2004).

### Table 2.3: Estimation results.

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(4a)</th>
<th>(4b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b$</td>
<td>41.733</td>
<td>5.244</td>
<td>17.978</td>
<td>18.25</td>
<td>17.475</td>
<td>16.589</td>
</tr>
<tr>
<td>$\phi$</td>
<td>0.723</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(.361)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\lambda$</td>
<td>-0.516</td>
<td>-0.321</td>
<td>-0.400</td>
<td>-0.401</td>
<td>-0.397</td>
<td>-0.392</td>
</tr>
<tr>
<td></td>
<td>(.021)</td>
<td>(.03)</td>
<td>(.023)</td>
<td>(.023)</td>
<td>(.023)</td>
<td>(.024)</td>
</tr>
<tr>
<td>Tobin’s $q$</td>
<td>5.314</td>
<td>1.441</td>
<td>2.512</td>
<td>2.534</td>
<td>2.391</td>
<td>2.391</td>
</tr>
<tr>
<td></td>
<td>1001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>1264</td>
<td>1178</td>
<td>1085</td>
<td>1001</td>
<td>633</td>
<td>1001</td>
</tr>
<tr>
<td>$R^2$</td>
<td>.163</td>
<td>.973</td>
<td>.689</td>
<td>.700</td>
<td>.597</td>
<td>.516</td>
</tr>
</tbody>
</table>

Non-linear least squares. Bootstrapped std. errors in parentheses. Column (1) represents the steady-state level equation. Column (2) represents the transition equation. Column (3) is the transition equation in first differences. Column (4) is the transition equation in first differences in first differences with control function for endogenous lagged dependent variables. Column (4a) is the transition equation in first with control function and observed $\phi$. Column (4b) is the transition equation in first difference ith control function in which we estimate the dividend payout ratio, $\phi$.

### 2.3.3 Robustness

**Endogenous and exogenous $\phi$**

To show that our results are not driven by the endogenous $\phi$ parameter in the model, we estimate Model (4) taking $\phi$ as an exogenous parameter. Therefore, we use the observed dividend payout ratio of a subset of 70 countries, the results are given in Column (4a).8 Alternatively, we take $\phi$ as an independent variable in the estimations in Column (4b). The results in terms of capital adjustment costs, $b$, speed of convergence, $\lambda$, and Tobin’s q are very similar in all Models (3) - (4b). Moreover, the $\phi$ observed

---

8See Appendix D for more detailed information about observed dividend payout ratios.
for the subset of 70 countries is very similar to the $\phi$ based on equation (2.38) and observed capital taxes. Lastly, the estimates for $\phi$ when taking it as an independent variable are not significantly different from the observed or endogenously derived dividend payout ratios.

**Rich and poor countries**

As an additional robustness check, we split our sample into rich and poor countries, defined by being over or below the sample median GDP per capita, and estimated our preferred specification (4) in the two subsamples, separately. The results for rich countries are almost identical: capital adjustment costs are 18.49, $\lambda$ is -0.402 and Tobin’s q is 2.55. The capital adjustment costs for poor countries are slightly lower with 14.46 and the convergence parameter is -0.379, while Tobin’s q is 2.21. Still, the results seem neither be driven by poor nor rich countries.

**Pre-financial-crisis results**

If we only use years before the financial crisis 2008 the capital adjustment costs are higher with 21.31, as well as Tobin’s q, 2.79, while $\lambda$ is -0.418. In general the results seem quite robust in terms of speed of convergence, $\lambda$, and capital adjustment costs, $b$.

**Effective tax rates**

In our estimations, we focus on using the statutory tax rates for two reasons. First, ex-ante effective tax rates include already a behavioral response of a model firm (e.g., its investment structure and its financing structure), and ex-post effective tax rates (i.e., the actual tax revenues generated from the average firm relative to the tax base) depend even more on firm-level responses (e.g., due to the location decisions and tax avoidance through transfer pricing, profit shifting and debt shifting). Second, the ratio of effective (average or marginal) tax rates to the statutory tax rates on corporate profits is stable over time and countries (see Appendix F). Nevertheless, we find comparable estimates to the preferred specification (4) using ex-ante effective tax rates for corporate profits instead of statutory ones as a further robustness check. In general effective av-
erage and marginal tax rates on corporate profits are lower than the statutory tax rates for various reasons. The estimate for the capital adjustment cost parameter $b$ is slightly lower (around 14 when using either one of the two effective tax rates) and the convergence parameter $\lambda$ in those alternative regressions is almost identical to the estimates in specification (4) that is based on statutory tax rates.

2.4 Simulation

We use the estimate of $b$ from the preferred Model (4) to calculate the dynamic adjustment in response to a counterfactual change in tax policy. The simulation analysis proceeds in two steps. First, it uses the observed data for the year 2008 and the 79 economies covered to calculate the underlying steady-state equilibrium that is consistent with those data and the estimates of $b$. This steady-state equilibrium serves as the benchmark equilibrium which we shock for each country separately by a counterfactual tax policy. Second, for the counterfactual tax policy relative to the tax instruments as of 2008, we compute the counterfactual steady-state equilibrium and adjustment path for each economy using the 2008 steady-state level of capital in efficiency units of labor from Step 1 as $\hat{k}_j(0)$ in equation (2.27). This is done separately for a reduction of each tax instrument ($\tau_p$, $\tau_d$, and $\tau_g$) by 10%, one at a time, as well as for a simultaneous reduction. The differential path after the shock and the steady-state equilibrium (i.e., the impulse-response functions) are at the heart of interest to this analysis.

2.4.1 Impulse-response functions for output and capital

Figures 2.5, 2.6, 2.7, and 2.8 present the dynamic adjustment processes for all 79 economies graphically (using point estimates of $b$ to calculate country specific $\lambda$ and ignoring imprecision of the estimates for illustration). All results are presented per unit of effective labor. Hence, changes in the growth rates only reflect the impact of changes in tax policy and disregard potentially simultaneous exogenous shocks of technological progress and population growth.
In the interest of brevity, we focus on a detailed discussion of the results where we cut all three tax rates by 10% simultaneously; see Figure 2.5. The model suggests that a reduction in any one of the individual tax instruments has a positive effect on capital accumulation. Accordingly, the cut of all three tax instruments should increase capital accumulation and growth rates as well. Quantitatively, we find that such a shock in tax policy increases the level of capital per unit of effective labor on average by 5.33% and at the median by 4.86%. The effect on the level of output per unit of effective labor is lower and output increases on average by 2.56% and at the median by 2.11%. The range of the effects on capital per unit of effective labor is rather wide with a minimum of 0% (for The Bahamas, which do not tax any base the three instruments pertain to) and a maximum effect of 17.19% (for Gabon). The interquartile range amounts to 3.68 percentage points. Clearly, the functional form of the growth equation implies that the heterogeneity in steady-state responses in capital per unit of effective labor entails a
heterogeneity in the speed of adjustment and, hence, the short-and-medium-run growth rates of capital and output. On average, the convergence parameter amounts to -0.390 and is not very different from the median of -0.402. 99% of the gap in output – due to a cut of 10% in the three tax instruments – is closed after 2.44 years on average (after 2 years at the median). Hence, there is a fast convergence towards the new steady state. Thus, the reduction of the three tax instruments has strong short-run effects. It increases capital growth on average by 1.03% (at the median by 0.90%) within 5 years after the change, but the effect diminishes (to virtually zero) after 5 years. In the short-run, countries could increase their capital stock per unit of effective labor by up to 2.84% (as it is predicted for Gabon) on average over 5 years.

While we discussed a simultaneous reduction of all tax rates in the previous paragraph, 10% reductions of the individual tax rates, one at a time, compare as follows. A change in the corporate profit tax rate has a much bigger effect on outcome of interest than one in the dividend tax rate or the capital gains tax rate (see Figures 2.6, 2.7, and 2.8): capital per unit of effective labor increases by 3.64% on average (by 3.40% at the median) in response to a reduction of the corporate profit tax rate, which is much higher than the effect of the dividend tax rate (with 0.46% on average and 0% at the median) or the one of the capital gains tax rate (with 1.01% on average and 0.95% at the median). The heterogeneity in the responses to shocks of the individual tax rates has two reasons. First, among the three tax instruments considered here, the corporate tax rate has the highest level in percentage points. Hence, a 10% decline implies a bigger percentage-point change. Second, the corporate tax rate, $\tau_p$, is hierarchically closer to the source (i.e., gross profits) than the dividend tax rate, $\tau_d$, or the capital gains tax rate, $\tau_g$. The reason is that the latter two tax rates implicitly – at least to some extent – tax residual profits in the form of dividend payments or retained earnings as discussed in Keuschnigg (2005). In terms of the speed of convergence or the time to close the output gap, all three instruments behave very similarly. Analogous to the general tax reduction, the growth effects occur mainly in the short-run. Capital per unit of effective labor grows on average by 0.70%, 0.09%, and 0.22% (by 0.65%, 0%, and 0.19% at the median) over a period of 5 years directly after a (separate) reduction of corporate profit tax rates, dividend tax rates, or capital gains tax rates, respectively.\footnote{Clearly, since the steady-state and the convergence equations are inherently nonlinear in their argu-}
In general, we find that a change in the tax policy can have significant and permanent level effects, while the growth effects are mainly in the short-run.

2.4.2 Impulse-response functions for consumption and welfare analysis

For calculating the effects of tax policy shocks on consumption and welfare, we use the net investment position (NIIP) in percent of GDP and the steady-state capital stock and output per unit of effective labor to calculate the initial asset holdings for each country from

\[ \hat{\nu}_j(0) = \tilde{y}_j \text{NIIP}_j + \tilde{k}_j. \]  

(2.49)
2.4. Simulation

Figure 2.7: Dynamics after a reduction of dividend taxation of 10% in the year 2008 for 79 countries. Output and capital per unit of effective labor.

We use the observed consumption share in GDP in the year 2008, \( \chi_j(0) = \frac{C_j(2008)}{Y_j(2008)} \), to compute a model-consistent steady-state level of consumption per unit of effective labor, \( \tilde{c}_j(0) = \chi_j(0)\hat{\nu}_j(0) \). Then, we derive the initial marginal utility of wealth as

\[
\hat{a}_j(0) = \frac{1}{\tilde{c}_j(0)} = \frac{1}{\chi_j(0)\hat{\nu}_j(0)}.
\]

(2.50)

For the initial values of \( \hat{\nu}_j(0) \) and \( \hat{a}_j(0) \), we calculate the steady-state levels that are consistent with \( \hat{k} \) and the tax structure as described in Appendix C. Given the path of \( \hat{\nu}_j(t) \), we obtain \( \hat{\nu}_j(t) \) and the level of consumption per unit of effective labor, \( \hat{c}_j(t) \).\(^{10}\)

The question is whether this implied level of \( \hat{c}_j(t) \) based on equation (2.40) using the

\(^{10}\)Recall that missing data on the net investment position are responsible for a loss of observations at the country level in this analysis. Accordingly, the consumption and welfare analysis can only be conducted for 21 of the otherwise 79 economies covered.
estimates of the steady-state and convergence equations for capital per unit of effective labor in conjunction with the marginal utility of wealth, $\hat{a}$, derived with observed consumption share data, compare sufficiently well with data on the level of consumption. We check this issue as follows. Given the observed tax policy in 2008, we compute the model out-of-estimation-sample prediction of consumption for the year 2009 based on the initial values and steady-states for 2008. The consumption share only indirectly enters through the marginal utility of wealth, $\hat{a}$. Figure 2.9 plots consumption (not per effective labor!) predicted from the model against the observed consumption in 2009. The figure suggests that measured consumption expenditures of 2009 in real terms are well predicted by the sluggishly adjusting model economies of 2008. A simple regression of the model real consumption for 2009 on the observed consumption obtains an $R^2$ of 0.86.

Figure 2.8: Dynamics after a reduction of capital gains tax of 10% in the year 2008 for 79 countries. Output and capital per unit of effective labor.
2.4. Simulation

Hence, while the model is estimated on data of capital per unit of effective labor, it works well also for consumption. This justifies using \( \hat{\nu}_j(0) \) and \( \hat{a}_j(0) \) as initial values to compute consumption and welfare effects.

Figure 2.10 shows the impulse-response functions for consumption and total asset holdings after a simultaneous reduction of the three tax instruments for the 21 countries for which we are able to compute the initial values for \( a_j(0) \) and \( \nu_j(0) \).

Again, we focus on a discussion of the effects of a simultaneous reduction of all three considered tax instruments by 10%. It turns out that, immediately after the tax cut, the consumption per unit of effective labor decreases dramatically. This has two reasons. First, lower capital taxation increases the capital accumulation. Hence, individuals consume less and save more, and total asset holdings increase as shown in the right panel of Figure 2.10. Second, lower tax rates imply an immediate decline of tax revenues and,

![Figure 2.9: Log final good consumption expenditures against log model consumption prediction. 21 countries, 2009.](image-url)
hence, lump-sum transfers, as capital adjustment is sluggish. The latter effect reverses later as the capital stock increases over time which raises the revenues (and associated lump-sum transfers) collected from the capital gains tax bases and also the other tax base. Still, the numerical results show that we are generally to the left of the peak of the Laffer curve with those tax rates, as in none of the countries the total tax revenues exceed the initial tax revenues in the long-run.

Quantitatively, for the 21 countries in the sub-sample, consumption per unit of effective labor increases in the long-run relative to the initial steady-state level of 2008 on average by 8.2% (at the median by 5.9%). The United States are predicted to enjoy the biggest gains (30.1%) while Canada is predicted to gain the least (1.12%) from the instituted policy.
The initial fall in consumption may lead to ambiguous welfare effects. We calculate the Hicksian equivalent payment for the sub-set of 21 countries after the general tax cut of 10%. We find that for 14 out of the 21 countries, the Hicksian equivalent payment is negative (in these countries the representative individual is willing to pay to implement the capital tax reduction, e.g., in Brazil, Germany, Indonesia, Luxembourg, and South Africa), while for other countries Hicksian equivalent payment is positive (in these countries the representative agent is willing to pay to avoid the capital tax reduction, e.g., Austria, Canada, Italy, Switzerland, and the United States). Turkey is willing to give up about 52% of the consumption per effective unit of effective labor in 2008 to enjoy the long-run benefits of a capital tax reduction, while Switzerland would need a 82% higher consumption per effective unit of labor in 2008 to compensate for the capital tax reduction.1112 This finding implies that for some countries a strictly positive capital taxation is optimal, which contrast the Judd (1985) and Chamley (1986), who find that in the long-run the optimal tax on capital is zero. Table 2.6 in Appendix H presents the numerical results in greater detail for the case of a general tax reduction of 10% after 2008.

The magnitude of welfare effects depends strongly on the country-specific macroeconomic fundamentals. For example, a lower initial net investment position and consequently lower domestic asset holdings make it more likely to loose from a reduction of capital taxation. Intuitively, if foreign individuals own more of the domestic capital, most of the taxes are paid by foreign individuals. A reduction of capital taxation decreases the lump-sum tax redistribution (mostly financed by foreign capital owners) to domestic individuals, which they do not incorporate in their savings decision and this leads to lower consumption in the short-run. Similarly, a higher capital share in income, higher growth rate of labor technology and population imply a faster speed of convergence and make it more likely to gain from a tax reduction. With a higher $|\lambda|$ the optimal capital stock is reached earlier and tax revenues and wages increase faster along the transition path.13

The higher long-run asset holdings and wages will reverse the consumption pattern in the long-run. Still the initial consumption drop may lead to negative welfare effects.14

---

11 Consumption is a numéraire and its price does not change after a change in the capital tax structure. In this case the Hicksian equivalent payment and the Hicksian compensation are the same.
12 The effects in terms of present discounted utility under the benchmark and counterfactual tax policies using real consumption per capita are similar.
13 Wages increase with the capital stock due to capital-labor-complementarity.
14 This effect is independent of the investment behavior of domestic individuals. Tax revenues and
Chapter 2. Capital Taxation, Investment, Growth, and Welfare

2.5 Conclusion

In this chapter we formulate a dynamic model of a small open economy to analyze the impact of broad capital taxation (through corporate profit taxes, dividend taxes, and capital gains taxes) for macroeconomic outcomes such as steady-state levels and growth transitions of the capital stock, output, consumption, and welfare.

The model is generally amenable to structural nonlinear estimation and it is informed by data of 79 economies for which the authors collected detailed panel data information on corporate profit tax rates, dividend tax rates, and capital gains tax rates, apart from macroeconomic variables for the years 1996-2011. The model may be used to estimate a capital adjustment cost parameter and the dividend payout ratio. In conjunction with data determining the steady-state level and the transition path of capital per effective unit of labor, these estimated parameters permit computing model-consistent values of the speed of convergence and of Tobin’s $q$. In the preferred specifications discussed in the essay, the estimated levels of the dividend payout ratio, of the speed of convergence, and of Tobin’s $q$ are well in line with data and with estimates reported in earlier work for selected countries. This makes the authors confident that the estimates may be used for counterfactual analysis of the dynamic effects of capital tax policy.

Important findings of this analysis are the following. First, macroeconomic outcomes appear to be more sensitive to a proportional change in corporate profit tax rates than in dividend or capital gains tax rates. The reason is that corporate profit tax rates are on average much higher than dividend or capital gains tax rates and, hence, they cause bigger distortions. However, the reason is also that dividend and capital gains taxes apply to residual profits (net of corporate profit tax) whereas corporate profit tax rates apply to gross profits.

wages only depend on the optimal capital stock and consequently on the firm’s capital adjustment path, which is the same for investment financed by domestic or foreign individuals.
The effects of a uniform (percentage-wise) effect of a tax reduction are quite heterogeneous across countries for two reasons, namely that both initial tax policy levels and macroeconomic fundamentals are inherently different across economies. For instance, simulated effects on steady-state capital stocks per unit of effective labor are bigger in percentage points than the median effect is in percent. Similar conclusions apply for the effects on output per effective unit of labor. Growth effects per unit of effective labor occur mainly in the short-run of up to 5 years, but effects on levels are economically quite significant for some economies.

Welfare is ambiguously affected by such broad capital tax policy in spite of the unambiguously positive effects on capital and output. The reason is that a reduction in tax revenues (and, hence, transfers to consumers) reduce consumption in the short-run and raise it in the long-run so that, on net, (representative consumers per unit of effective labor in) some countries are found to loose while others are found to gain. From that perspective, some countries (such as Austria, Canada, Switzerland, and the United States) should be inclined to raise capital tax rates while others (such as Brazil, Germany, Indonesia, Luxembourg, and the South Africa) should be inclined to reduce them.
Appendix

A Change in total value of equity

We define
\[ E \equiv E^d + E^f \quad \text{and} \quad D \equiv D^d + D^f. \]  \hspace{1cm} (2.51)

After taking the time derivative of \( V = qE \),
\[ \frac{\partial V}{\partial t} = \dot{V} = \dot{q}E + q\dot{E}, \]  \hspace{1cm} (2.52)

we may substitute \( R \) from equation (2.13) in equation (2.11) and solve for \( q\dot{E} \):
\[ q\dot{E} = D + \dot{K} + \delta K - (1 - \tau_p)\Pi. \]  \hspace{1cm} (2.53)

Substituting (2.53) in equation (2.52) obtains
\[ \dot{V} = \dot{q}E + D + \dot{K} + \delta K - (1 - \tau_p)\Pi \]  \hspace{1cm} (2.54)

which, after defining \( \gamma \equiv (1 - \tau_p)\Pi - \dot{K} - \delta K \), may be written as
\[ \dot{V} = \dot{q}E + D - \gamma. \]  \hspace{1cm} (2.55)

We then may solve (2.5) for \( \ddot{q} \) using the arbitrage condition from the FOCs in equations (2.5) and (2.6):
\[ \ddot{q} = \frac{r}{1 - \tau_g}q - \frac{1 - \tau_d}{1 - \tau_g}\frac{D^d}{E^d}. \]  \hspace{1cm} (2.56)

Substituting this in equation (2.55) and using \( V \equiv qE \) as well as that the dividend yields are the same for domestic and foreign individuals, \( \frac{D^d}{V^d} = \frac{D^f}{V^f} \), which implies that
$$E^d D^f = E^f D^d$$, obtains

$$\dot{V} = \frac{r}{1 - \tau_g} V - \frac{1 - \tau_d D^d}{1 - \tau_g} \left( E^d + E^f \right) + D - \gamma$$

$$= \frac{r}{1 - \tau_g} V - \frac{1 - \tau_d D^d E^d + D^f E^d}{E^d} + D - \gamma$$

$$= \frac{r}{1 - \tau_g} V - \frac{1 - \tau_d}{1 - \tau_g} D + D - \gamma$$

$$= \frac{r}{1 - \tau_g} V + \left( 1 - \frac{1 - \tau_d}{1 - \tau_g} \right) D - \gamma$$

$$= \frac{r}{1 - \tau_g} V - \left( \frac{\tau_d - \tau_d}{1 - \tau_g} \right) D - \gamma,$$

which gives equation (2.14). Last, note that as in Turnovsky and Bianconi (1992) in equilibrium $$qE = K$$ and, hence, $$qE = R$$.

### B Transfers

We write total tax revenues, $$F$$, as a function of capital:

$$F = \tau_p \pi + \tau_d D + \tau_g \dot{q} E$$

$$= \tau_p \pi + \tau_d \phi (1 - \tau_p) \pi + \tau_g E \left( \frac{r}{1 - \tau_g} q - \frac{1 - \tau_d D}{1 - \tau_g} \right)$$

$$= (\tau_p + \tau_d \phi (1 - \tau_p) - \frac{\tau_g}{1 - \tau_g} (1 - \tau_d)(1 - \tau_p) \phi) \pi + \frac{\tau_g}{1 - \tau_g} r K.$$ (2.58)

Tax revenues per unit of effective labor, $$\dot{f}$$, are given by

$$\dot{f} = (\tau_p + \tau_d \phi (1 - \tau_p) - \frac{\tau_g}{1 - \tau_g} (1 - \tau_d)(1 - \tau_p) \phi) \left( \alpha \dot{k}^\alpha - \frac{b}{2} \left( \frac{\dot{k}}{k} \right)^2 \right) + \frac{\tau_g}{1 - \tau_g} r \dot{k}.$$ (2.59)

### C Consumption

The change of asset holdings per unit of effective labor is given by

$$\dot{\nu} = \dot{w} + (r - x) \dot{\nu} + z \dot{f} - \ddot{c},$$ (2.60)
where \( z \in [0, 1] \) gives the share of tax revenues that is actually redistributed, \( \hat{w} = (1 - \alpha)f(\tilde{k}) \), and \( \hat{c} \) is the consumption per efficiency unit of labor. We linearize this equation around its steady state to obtain:

\[
\dot{\nu} \approx (\hat{w} \hat{k}(\tilde{k}) + z \hat{f}(\tilde{k})) (\hat{k}(t) - \tilde{k}) - \hat{c}_a(\tilde{a}) (\hat{a}(t) - \tilde{a}) + (r - x)(\hat{v}(t) - \tilde{v}). \tag{2.61}
\]

From the FOC use that

\[
\dot{a} = (\rho - n - x - (1 - \tau_p) \Pi_k (1 - \tau_d) \phi + (1 - \tau_g)(1 - \phi))a, \tag{2.62}
\]

which we linearize to obtain

\[
\dot{a} \approx (((1 - \tau_d) \phi + (1 - \tau_g)(1 - \phi))(1 - \tau_p) \alpha (1 - \alpha) \hat{k}^{a-2}(\hat{k}(t) - \tilde{k})) \hat{a}, \tag{2.63}
\]

where we assume that the shadow value of capital, \( \eta \), immediately adjusts to the new steady state. We substitute \( \hat{k}(t) - \tilde{k} = (\hat{k}(0) - \tilde{k}) \exp(\lambda t) \) and solve the differential equation, which leads to

\[
\hat{a}(t) = \tilde{a} \exp(-\zeta t), \tag{2.64}
\]

where \( \zeta = \left( \alpha (1 - \alpha) \hat{k}^{a-2}((1 - \tau_d) \phi + (1 - \tau_g)(1 - \phi))(1 - \tau_p) \right) (\hat{k}(0) - \tilde{k}) \exp(\lambda t) \). If capital is in its steady state, \( \zeta = 0 \) and, hence, \( \exp(\zeta t) = 1 \). Extending equation (2.64) yields

\[
\hat{a}(t) - \tilde{a} = \tilde{a}(\exp(-\zeta t) - 1). \tag{2.65}
\]

We substitute \( \hat{k}(t) - \tilde{k} \) and \( \hat{a}(t) - \tilde{a} \) in equation (2.61) and solve the differential equation to obtain

\[
\hat{v}(t) = \tilde{v} + \frac{1}{\lambda - r + x} \exp(\lambda t) \left( \hat{w}_k(\tilde{k}) + z \hat{f}_k(\tilde{k}) \right) (\hat{k}(0) - \tilde{k}) + \frac{1}{\tilde{a}} \left( \frac{1}{r - x} + \frac{1}{\zeta - r + x} \exp(-\zeta t) \right). \tag{2.66}
\]

For a given \( \tilde{a}, \tilde{v}, \) and \( \hat{k}(0) \), we may calculate the level and change of total assets, \( \hat{v}(t) \) and \( \dot{v} \), respectively, the level of consumption, \( \hat{c}(t) \), all in units of effective labor, at each point in time.
D Taxes

D.1 Corporate profit tax rates ($\tau_p$)

For corporate profit taxes, we utilize the maximum tax rate levied at the national level on corporate profit in a country of residence. In federal states, the total corporate tax rate is calculated as the weighted average of the local (subnational) taxes combined with federal tax rates (e.g., for Germany or Canada as reported by the OECD) or the tax rate prevailing in the economic center (e.g. for Switzerland, where the rates of the canton of Zurich are taken).

The primary sources for corporate profit tax rates are the following:

- OECD [www.taxfoundation.org](http://www.taxfoundation.org)

D.2 Capital gains tax rates ($\tau_g$)

For corporate capital gains taxes, we utilize the maximum tax rate levied at the national level on corporate capital gains in a country of residence.

The primary sources for corporate capital gains tax rates are the following:

D.3 Dividend tax rates ($\tau_d$)

For corporate dividend taxes, we utilize the maximum tax rate levied at the national level on after-tax income, classified as dividends, which are distributed to (mostly corporate) shareholders. Shareholder taxation is not taken into account. If an imputation system (as, e.g., in Australia) is stated in the tax code the tax rate on dividends is set to 0. In some cases tax codes allow for differentiated dividend tax rates conditional on holding requirements of the recipient. Here we choose tax rates applied to dividends paid to corporations holding 10% or less of the distributing entity. In such cases dividend taxation decreases with higher shares held by the receiving entity and our dividend tax rates represent the upper bound.

The primary sources for corporate dividend tax rates are the following:

- Ernest and Youn g *Worldwide Corporate Tax Guide* 1998-2012

E Corporate dividend payout ratio ($\phi$)

We use the measured time-invariant (rather than the implied) dividend payout ratio, $\phi$, as a robustness check for the results. To collect the corresponding data we took for each country the total dividends paid by each firm over the whole sample period from Standard and Poor’s Compustat data-set and divided them by the total profits of each firm over the whole sample period. Compustat contains almost 24,000 companies in 70 countries between 1996 and 2012. We excluded firms where either dividend payments or income was missing or negative. Summary statistics for these variables are provided in Table 2.4.
### Table 2.4: Dividend payout ratio. Summary statistics.

<table>
<thead>
<tr>
<th>Variable</th>
<th># Obs.</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi$</td>
<td>70</td>
<td>0.612</td>
<td>0.568</td>
<td>0.081</td>
<td>4.018</td>
</tr>
<tr>
<td>Total dividends per country</td>
<td>70</td>
<td>3.10e+11</td>
<td>6.12e+11</td>
<td>1.54e+8</td>
<td>3.23e+12</td>
</tr>
<tr>
<td>Total profits per country</td>
<td>70</td>
<td>9.85e+11</td>
<td>2.85e+12</td>
<td>1.80e+8</td>
<td>1.99e+13</td>
</tr>
</tbody>
</table>

*Standard and Poor’s Compustat, 1996 - 2012, 70 countries.*

The share of corporate after-tax profits which is paid as dividends to shareholders is calculated as:

$$
\phi_j = \frac{\text{Total dividends}}{\text{Net income}} = \frac{\sum_{t=0}^{T} \sum_{s_j=0}^{S_j} D_s(t)}{\sum_{t=0}^{T} \sum_{s_j=0}^{S_j} I_s(t)},
$$

(2.67)

where $s_j = 1, 2, ..., S_j$ indicate firms in country $j$ and $T = 17$ years (1996-2012).

- **Total dividends**: To calculate total dividends we use the annual amount of dividends in current million USD from the corporate income statement as stated in Standard and Poor’s Compustat database.
- **Net income**: To calculate net income we use annual income after all expenses in current million USD from the corporate income statement as stated in Standard and Poor’s Compustat database.

### F Net investment position (NIIP)

The International Monetary Fund (IMF) defines the NIIP as the stock of external assets less the stock of external liabilities. It gives the difference between what an economy owns in relation to what it owes. Table 2.5 shows the net investment position for 21 countries.

### G Ratio effective average (marginal) to statutory corporate profit tax

Figure 2.11 plots the ratio of effective average (marginal) to statutory corporate profit taxes for our sample over the period between 1996 and 2011. The ratios stay relatively
constant over time. The median ratio of the effective average corporate profit tax decreases from 0.944 in 1996 to 0.939 in 2011. Similarly, the median ratio of the effective marginal corporate profit tax decreases from 0.830 in 1996 to 0.800 in 2011.

![Whisker plot of the ratio of effective average (marginal) to statutory corporate profit tax rate. 79 countries, 1996 - 2011.](image)

**Table 2.5: Net investment position (NIIP)**

<table>
<thead>
<tr>
<th>Country</th>
<th>NIIP</th>
<th>Country</th>
<th>NIIP</th>
<th>Country</th>
<th>NIIP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>-56.9</td>
<td>Indonesia</td>
<td>-32.7</td>
<td>Spain</td>
<td>-79.3</td>
</tr>
<tr>
<td>Austria</td>
<td>-17</td>
<td>Ireland</td>
<td>-71.9</td>
<td>Switzerland</td>
<td>115.6</td>
</tr>
<tr>
<td>Belgium</td>
<td>39.8</td>
<td>Italy</td>
<td>-24.1</td>
<td>Sweden</td>
<td>-11.1</td>
</tr>
<tr>
<td>Brazil</td>
<td>-21.7</td>
<td>Japan</td>
<td>45.1</td>
<td>South Africa</td>
<td>-9</td>
</tr>
<tr>
<td>Canada</td>
<td>-7.5</td>
<td>Luxembourg</td>
<td>120.7</td>
<td>Turkey</td>
<td>-32.1</td>
</tr>
<tr>
<td>France</td>
<td>-12.9</td>
<td>Mexico</td>
<td>-35.9</td>
<td>United Kingdom</td>
<td>-6.9</td>
</tr>
<tr>
<td>Germany</td>
<td>25.5</td>
<td>Netherlands</td>
<td>4.2</td>
<td>United States</td>
<td>-22.1</td>
</tr>
</tbody>
</table>

Lesotho 25 25 0 1.087 1.260 1.100 0.041 0.257 0.001 1.304 0.115 0.714 0.003 -0.434 1 -0.434 1
Luxembourg 30 30 15 1.173 1.447 1.207 0.096 0.590 0.003 1.546 0.222 1.372 0.007 0.917 4.778 -3.225 -0.425 3
Morocco 28 28 10 1.340 2.039 1.345 0.014 0.063 0.001 2.059 0.034 0.202 0.001 -0.387 0 0 -0.402 4
Malta 35 35 0 1.280 1.726 1.319 0.099 0.599 0.004 1.843 0.220 1.328 0.008 0.401 3 -0.401 3
Mauritania 25 25 16 1.313 1.816 1.346 0.083 0.503 0.003 1.918 0.183 1.107 0.007 0.404 3 -0.404 3
Mexico 28 28 0 1.184 1.508 1.209 0.070 0.453 0.002 2.391 0.183 1.058 0.007 0.395 2 0.395 2
Moldova 10 10 0 1.345 2.039 1.345 0.014 0.083 0.001 2.059 0.034 0.202 0.001 -0.387 0 0 -0.402 4
Macedonia 25 25 16 1.313 1.816 1.346 0.083 0.503 0.003 1.918 0.183 1.107 0.007 0.404 3 -0.404 3
Morocco 28 28 0 1.184 1.508 1.209 0.070 0.453 0.002 2.391 0.183 1.058 0.007 0.395 2 0.395 2

Initial taxes are for the base year 2008 and are reduced by 10%. Time horizon is 30 years, 2008 - 2037. $\gamma$ gives an approximation for the discounted utility $\gamma^{t}_{z}$; $\gamma^{t \prime}_{z}$ gives the average growth rate of the variable $z$ between $t$ and $t'$. $\lambda$ is the country specific convergence parameter. Gap indicates the number of years until 99% of the gap between the base line output and the new steady-state output is closed. $\hat{y}$, $\hat{k}$ and $\hat{c}$ are measured in units of effective labor.
Bibliography


3. Trade Effects of Within-Country Income Inequality

3.1 Introduction

Since the well-known Linder (1961) hypothesis, many economists investigated the effects of inequality on trade patterns. While Linder’s research was mainly descriptive, models with non-homothetic preferences became popular in the late 1980s. Especially, the work of Hunter and Markusen (1988), Markusen (1986), Bergstrand (1990), and Hunter (1991) drew attention to the importance of non-homothetic preferences for trade flows focusing on between country income differences in terms of GDP per capita.\footnote{See Markusen (2013) for a summary of many applications of non-homothetic preferences in trade theory.}

More recently, Fieler (2011) implements non-homothetic preferences into an Eaton and Kortum (2002) trade model for differentiated goods to investigate the effects of income difference between countries. Similarly, Caron et al. (2014) extend the model of Fieler (2011) to investigate how demand of goods with different characteristics, such as skilled-labor intensity or tradability, varies with per capita income.

If income differences between countries have an effect on consumption and trade patterns, within-country income inequality should have an effect too. With non-homothetic preferences the consumption pattern of an individual depends on the income level – (relative) consumption shifts from necessities and normal goods to luxury goods if income increases. Consider the stylized case of two economies, which have the
same GDP per capita. In the first economy all income is earned by one individual and this individual spends most of its income on luxury goods. In the second economy, the income is distributed equally among all individuals and each individual mainly consumes necessities. Although the two economies have the same GDP per capita, the (aggregate) consumption pattern (and trade pattern) might differ significantly between them. Francois and Kaplan (1996) formalize the intuition that the income distribution is an important determinant of aggregate expenditure, but only provide mixed empirical evidence on the impact of within-country inequality on trade patterns. In a more recent empirical study Dalgin et al. (2008) find that, everything else equal, more income equality leads to higher imports of necessities. While Francois and Kaplan (1996) and Dalgin et al. (2008) focus on the income distribution of the importer, Martínez-Zarzoso and Vollmer (2012) and Bernasconi (2013) consider the income distribution of the exporter as well. They find that if the income distributions of two trading countries are similar these countries trade more at the intensive and extensive margins.

Most of these empirical studies on within-country inequality and trade are not based on explicit theoretical models, but refer to non-homothetic preferences as a theoretical explanation. Matsuyama (2000) develops a model of North-South trade based on Flam and Helpman (1987) where the income distribution determines which goods are produced in the South (North) and consumed in the South (North). Similarly, Foellmi et al. (2011) use a hierarchical demand function to investigate the effects of within-country inequality. In Matsuyama (2000) and Foellmi et al. (2011) individuals extend the number of different goods they consume with their income, which directly relates the income distribution with the extensive margin of goods consumed, produced and traded. Mitra and Trindade (2005) only consider two types of goods in a two-country Heckscher-Ohlin trade model with non-homothetic preferences. These two goods are substitutes and changes in the income distribution change the intensive margin of consumption. Most theoretical models only consider two income groups (rich and poor) to describe inequality and the resulting trade patterns, as introducing a greater heterogeneity in income in combination with non-homothetic preferences often leads to less tractable aggregate demand functions. Limiting the analysis to two income groups makes these models tractable, but does not allow to directly quantify their results.
I develop a two-sector trade model with non-homothetic preferences that incorporates within-country inequality in a monopolistic competition trade model à la Krugman (1979, 1980). Individuals in the model are heterogeneous in terms of their income and countries differ in their income distribution. The model allows to consider income distributions with an arbitrary number of income classes without loss of tractability. The model provides an explanation why countries with similar income distributions trade more. It shows, that under certain conditions, increasing the equality in a country has a positive impact on bilateral imports and exports of this country. Moreover, I directly estimate the degree of non-homotheticity of the utility function. In a quantitative exercise I show that the elasticity of exports with respect to within-country equality is close to unity, emphasizing the importance of the income distribution for trade patterns. Furthermore, increasing the equality in a country does not only increase imports and exports of this country, but has negative spill-over effects on trade between all other countries. Last, within the model gains from trade are higher for poorer individuals, as their expenditure share for tradable goods is higher. This differs from the results of Nigai (2013) and Khandelwal and Fajgelbaum (2013), who find that in general gains from trade are lower or even negative for poorer individuals.

In contrast to previous theoretical models I focus mainly on the within-country inequality, although between-country inequality is as well an important factor for trade patterns (see Fieler, 2011, Markusen, 2013 or Caron, Fally and Markusen, 2014). The model in this paper allows for heterogeneity of income within a country using Price-Independent Generalized Linear (PIGL) utility function (see Muellbauer, 1975, Deaton and Muellbauer, 1980) to aggregate the individual demands over heterogeneous individuals and to directly relate aggregate demand to the income distribution in the economy as in Boppart (2013). With PIGL preferences the aggregate demand functions include one parameter that summarizes the (continuous) income distribution in the economy.\(^2\) Depending on the parameterization PIGL preferences can either have linear or non-linear Engel curves, which is a testable feature of the model. Moreover,

\(^2\)In the empirical section I use only 10 income classes for reasons of data availability. Theoretically I can consider a continuous income distribution.
the model is suitable for structural estimation of the key parameters of the model, which allows to directly relate the model to data.

The basic setup of the model is similar to Boppart (2013), but while Boppart (2013) analyses structural change and the Kuznets curve in an growth model, I analyse the effects of different income distributions on bilateral trade flows. In the model individuals consume manufacturing goods and services. Manufacturing goods are assumed to be tradable and services are non-tradable. With a non-homothetic (PIGL) preference structure the demand for services relative to manufacturing goods increases with (individual) income, while with homothetic preferences relative demand is constant. In terms of within-country inequality (for a given GDP per capita) countries with less income inequality demand relatively more manufacturing goods than countries with higher income inequality. Hence, countries with a more equal income distribution have a greater market for manufactures and consume, produce, export and import more manufacturing goods than a country with a less equal income distribution and the same GDP per capita. In this sense the model relates the relative demand to the industry structure and is in line with models that explore the effects of inequality on structural change, see for example Foellmi and Zweimüller (2006), Foellmi and Zweimüller (2008), Matsuyama (2009), Fajgelbaum et al. (2011), and Boppart (2013).

As the model is amenable to structural estimation, I use the estimated parameters to calibrate a multi-country trade model that fits bilateral trade data very well. The correlation between the observed bilateral trade flows of 13 OECD countries and the trade flows predicted by the calibrated model is 0.83. Hence, the framework appears highly suitable for quantitative counterfactual analysis.

The remainder of the essay is structured as follows. Section 3.2 introduces the theoretical model in a closed and open economy. In section 3.3 I present some empirical evidence and estimate the structural parameters of the model. In section 3.4 I show the results for a calibrated multi-country trade model. Finally, section 3.5 concludes.
3.2 Model

3.2.1 Preferences

There are $j = 1, ..., N$ individuals in the economy that differ in their labor endowment. Each individual $j$ inelastically supplies $l_j \geq 0$ units of labor. The total labor supply of the economy is $L = \sum_{1}^{N} l_j$. The wage rate, $w$, is the same for all individuals, but individual income, $y_j = wl_j$, is heterogeneous as the individual labor endowment is heterogeneous. Following Muellbauer (1975) all individuals have the following indirect utility function over a (composite) manufactured good, $m$, and services, $s$:

$$V(P_m, P_s, y_j) = \frac{1}{\epsilon} \left( \frac{y_j}{P_s} \right)^\epsilon - \frac{\tilde{\beta}}{\gamma} \left( \frac{P_m}{P_s} \right)^\gamma,$$

where $P_s$ is the price of services and $P_m$ is the price index of the (composite) manufacturing good. The parameters of the utility function are restricted to $0 \leq \gamma, \epsilon \leq 1$ and $\tilde{\beta} > 0$. We can interpret $\epsilon$ as the degree of non-homotheticity in the model, where $\epsilon = 0$ implies homothetic preferences. $1 - \epsilon$ gives the income elasticity of the manufactured good. Using Roy’s identity the demands $c_{jm}$ and $c_{js}$ of an individual $j$ are:

$$c_{jm} = -\frac{\partial V}{\partial P_m} \left( \frac{\partial V}{\partial y_j} \right) = \frac{\tilde{\beta} y_j}{P_m} \left( \frac{P_s}{y_j} \right)^\epsilon \left( \frac{P_m}{P_s} \right)^\gamma,$$

$$c_{js} = -\frac{\partial V}{\partial P_s} \left( \frac{\partial V}{\partial y_j} \right) = \frac{y_j}{P_s} \left[ 1 - \frac{\tilde{\beta}}{\gamma} \left( \frac{P_s}{y_j} \right)^\epsilon \left( \frac{P_m}{P_s} \right)^\gamma \right].$$

The preferences are only well defined if the income is sufficiently high, such that the demand for manufactures and services is positive, which is the case if $y \geq \frac{1 - \epsilon}{1 - \tilde{\beta} \gamma \frac{P_m}{P_s}}.$

Figure 3.1 plots the (individual) Engel curves for manufactures and services. Demand for manufactures and services is strictly increasing in income. The parameter $\epsilon$ determines the curvature of the Engel curves.

---

3It is easy to show that the preferences satisfy adding up and separability. The income elasticity of the service sector is given by $\frac{1 - (1-\epsilon)\tilde{\beta}(\frac{P_m}{P_s})^\gamma}{1 - \tilde{\beta}(\frac{P_m}{P_s})^\gamma}.$
If $\epsilon > 0$, Engel curves are non-linear for manufactures and services, indicating non-homothetic preferences. If $\epsilon = \gamma = 0$, the demand functions simplify to Cobb-Douglas demand functions with linear Engel curves through the origin.\footnote{In Appendix A I show that for OECD countries the shape of the Engel curves from PIGL preferences (with $\epsilon > 0$) are consistent with the observed consumption of manufactured and services in the sense that relative consumption of services increases with income.}

Figure 3.1: (Individual) demand for manufactures and service: Engel curves. PIGL utility function. Exogenous prices.
I obtain the aggregate demand in the economy by taking the sum over all individuals in the economy.

\[ c_m = \sum_{j=1}^{N} c_{jm} = \beta P_m^{-1} P_s^\epsilon \left( \frac{P_m}{P_s} \right) \gamma \sum_{j=1}^{N} y_j^{1-\epsilon}, \tag{3.4} \]

\[ c_s = \sum_{j=1}^{N} c_{js} = \frac{Y}{P_s} - \beta P_s^{-1} \left( \frac{P_m}{P_s} \right) \gamma \sum_{j=1}^{N} y_j^{1-\epsilon}, \tag{3.5} \]

where \( c_m \) and \( c_s \) are the aggregated demands for manufactures and services, respectively. For empirical purposes I divide the population in \( K \geq 1 \) income classes of equal population size, where I assume that in each income class labor endowment (income) is homogeneous. Total income is given by

\[ Y = \sum_{j=1}^{N} y_j = \frac{K}{N} \sum_{k=1}^{K} N y_k, \tag{3.6} \]

where \( y_k \) is the (average) income of individuals in class \( k \) and \( \frac{N}{K} \) is the size of each income class. Rewriting equations (3.4) and (3.5) for \( K \) income classes yields

\[ c_m = \sum_{j=1}^{N} c_{jm} = \beta P_m^{-1} P_s^\epsilon \left( \frac{P_m}{P_s} \right) \gamma w^{1-\epsilon} L \phi, \tag{3.7} \]

\[ c_s = \sum_{j=1}^{N} c_{js} = \frac{Y}{P_s} - \beta P_s^{-1} \left( \frac{P_m}{P_s} \right) \gamma w^{1-\epsilon} L \phi, \tag{3.8} \]

where in order to interpret average GDP per capita, \( y \), as the wage rate, \( w \), I normalize the total labor endowment, \( L \), to be equal to the number of individuals, \( \frac{N}{K} \beta = \frac{\beta}{K} \) and \( \phi \) is an equality measure of the economy defined as

\[ \phi = \frac{1}{K} \sum_{k=1}^{K} \left( \frac{y_k}{y} \right)^{1-\epsilon} = \frac{1}{K} \sum_{k=1}^{K} \left( \frac{w l_k}{w} \right)^{1-\epsilon} = \frac{1}{K} \sum_{k=1}^{K} l_k^{1-\epsilon}, \tag{3.9} \]

where \( l_k \) is the labor endowment of the (average) individual in income class \( k \). A more unequal distribution of labor endowments (more unequal distributions of income for a given wage rate, \( w \)) implies a lower \( \phi \). Consider the case in which all income is earned

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5Total GDP is simply \( Y = wL \), while GDP per capita is \( y = Y/N \). It follows directly that if \( N = L \), then \( y = w \) independent of the individual distribution of labor endowment.
by one individual, then $\phi = 1$. If all individuals earn the same income (have the same labor endowment), then $\phi = \sum_{k=1}^{K} \left( \frac{L}{N} \right)^{1-\epsilon} = K^\epsilon$, is the value of $\phi$ under perfect equality. As $K$ goes to $N$ the income classes get smaller until each class consists of one individual and $\phi$ reflects the complete income distribution. $\epsilon \in [0, 1]$ reflects the inequality aversion of the equality index $\phi$. The higher is $\epsilon$ the more sensitive is $\phi$ to changes in the income shares. Boppart (2013) shows that $\phi$ can be related to the inverse of the Atkinson inequality index. If $\epsilon \neq 0$, within-country inequality has an impact on the aggregate demand for manufactures and services, while for homothetic preferences ($\epsilon = 0$) inequality does not matter in the model as $\phi = 1$ and the aggregate demands only depend on aggregate income. It is straightforward to derive the (aggregate) expenditure shares for manufactures and services:

$$S_m = \frac{P_m c_m}{w L} = \beta P_s \left( \frac{P_m}{P_s} \right)^\gamma w^{-\epsilon} \phi,$$

(3.10)

$$S_s = \frac{P_s c_s}{w L} = 1 - \beta P_s \left( \frac{P_m}{P_s} \right)^\gamma w^{-\epsilon} \phi.$$

(3.11)

The expenditure share for manufactures decreases in GDP per capita and increases in the income inequality parameter $\phi$ for a given price index $P_m$. Conversely, the expenditure share for services increases in GDP per capita and decreases in the income equality parameter $\phi$.

### 3.2.2 Labor market

Manufactures and services are produced with labor as the only input. I assume that services are produced with constant returns to scale and are consumed only locally (non-tradable). $a_s$ is the labor requirement in the services sector. The wage rate, $w$, is given by $w = a_s P_s$. Labor is completely mobile between the two sectors and hence the wage rate applies as well in the $m$ sector. I denote the share of labor in that sector by $L_m$. The total labor employed in manufacturing is $L_m L$. Market clearing in the service sector implies that production equals demand:
3.2. Model

\[ c_s = (1 - L_m)La_s. \]  

(3.12)

I use equation (3.8) to express the share of labor allocated to manufacturing as a function of prices, income per capita, total labor supply, and equality, see Appendix B for more details.

\[ L_m = \beta w^{\gamma} a_s^{\gamma-\epsilon} P_m^\gamma \phi. \]  

(3.13)

For a given income per capita and price index of manufactured goods and labor productivity in the service sector, increasing \( \phi \) (equality), increases the labor share in manufacturing. This effect is driven by the demand side as more equality increases the demand for manufactures as shown in equation (3.7). As the price index, \( P_m \), will depend positively on the wage rate, \( w \), the effect of an increasing wage rate is ambiguous at this point and will be discussed later.

3.2.3 Production

The composite manufacturing good, \( c_m \), is produced by intermediate manufacturing goods, \( c_q \), using a constant elasticity of substitution (CES) production function. I derive the demand for intermediate manufacturing goods by maximizing the function

\[ c_m = \left( \int_{\Omega} \frac{c_q^{\sigma-1}}{c_q} \, dq \right)^{\frac{\sigma}{\sigma-1}} \]  

(3.14)

s.t. \[ \int_{\Omega} p_q c_q \, dq = wLS_m, \]

where \( \sigma > 1 \) is the constant elasticity of substitution and \( p_q \) is the price of the manufactured good \( q \). Intermediate goods firms take the price index of the composite manufactures as well as average income and the income distribution, which is included in the \( S_m \) variable, as given. This setup is similar to a Krugman (1979, 1980) model. The demand for each (intermediate) manufactured good, \( c_q \), is given by:

\[ c_q = \frac{p_q^{\sigma}}{P_m^{1-\sigma}} S_m w L, \]  

(3.15)
where the price index $P_m$ is

$$P_m = \left( \int_\Omega p_1^{1-\sigma} dq \right)^{\frac{1}{1-\sigma}}. \quad (3.16)$$

The demand for each variety depends on the average income and the equality measure as the expenditure share of the (composite) manufactured good, $S_m$, is a function of $w$ and $\phi$. Each intermediate manufactured good is produced by an individual firm under monopolistic competition. Each firm has to cover its fixed costs, $f$, in terms of labor units. Marginal costs (in terms of labor) for each firm are $\frac{c_q}{\psi}$. The total costs of production in units of labor are $TC = f + \frac{1}{\psi}c_q$. The constant optimal price is:

$$p = p_q = \frac{\sigma}{\sigma - 1} \frac{w}{\psi} \forall q. \quad (3.17)$$

By symmetry the price index in the $m$-sector is:

$$P_m = \left( n \left( \frac{\sigma}{\sigma - 1} \frac{w}{\psi} \right)^{1-\sigma} \right)^{\frac{1}{1-\sigma}} = n^{\frac{1}{1-\sigma}} \frac{\sigma}{\sigma - 1} \frac{w}{\psi}, \quad (3.18)$$

where $n$ gives the number of intermediate manufactures or the number of intermediate producers in the economy. Profits for each (intermediate) manufactured good are given as:

$$\pi_q = p_q c_q - \left( fw + \frac{w}{\psi}c_q \right) = w \left( \frac{c_q}{(\sigma - 1)\psi} - f \right). \quad (3.19)$$

Free entry ensures that each firm in the market has zero profits.

$$\pi_q = 0 \Rightarrow c_q = (\sigma - 1)\psi f \quad \forall q. \quad (3.20)$$

The number of firms in the $m$-sector is derived using the labor market clearing condition:

$$n \left( f + \frac{c_q}{\psi} \right) = L_m L, \quad (3.21)$$

$$n = \frac{L_m L}{\sigma f}. \quad (3.22)$$

In equilibrium $n$ firms produce and sell for price $p$. 
I express the employment share in the \( m \)-sector in terms of the number of firms and the equality parameter, \( \phi \), using equations (3.13) and (3.18):

\[
L_m = \beta a_s^{\gamma-\epsilon} \left( \frac{\sigma}{\sigma - 1} \right)^{\gamma} \psi^{-\gamma} n^{1-\sigma} \phi. \tag{3.23}
\]

Substituting this in equation (3.22) and solving for \( n \) yields:

\[
n = \left( \frac{L}{\sigma f} \beta a_s^{\gamma-\epsilon} \left( \frac{\sigma}{\sigma - 1} \right)^{\gamma} \psi^{-\gamma} \phi \right)^{\frac{1-\sigma}{1-\sigma-\gamma}}. \tag{3.24}
\]

The optimal number of firms in autarky is a function of the equality measure and the labor productivity in the manufacturing and service sector. For \( \sigma > 1 \) the number of firms in the \( m \)-sector increases with \( \phi \) and \( L \). The labor share in manufacturing can be expressed in terms of the equality measure and the sectoral labor productivity using equations (3.24) and (3.23):

\[
L_m = \left( \frac{L}{\sigma f} \right)^{\frac{\gamma}{1-\sigma-\gamma}} \beta a_s^{\gamma-\epsilon-1} \left( \frac{\sigma}{\sigma - 1} \right)^{\gamma} \psi^{-\gamma} \phi^{\frac{1-\sigma}{1-\sigma-\gamma}}
\]

\[
= (\sigma f)^{\frac{-\gamma}{1-\sigma-\gamma}} (L)^{\frac{-\gamma}{1-\sigma-\gamma}} \left( \beta \left( \frac{\sigma}{\sigma - 1} \right)^{\gamma} \right)^{\frac{1-\sigma}{1-\sigma-\gamma}} \psi^{-\gamma(1-\sigma)} \phi^{\frac{1-\sigma}{1-\sigma-\gamma}} a_s^{\frac{(1-\sigma)(\gamma-1)}{1-\sigma-\gamma}} \tag{3.25}
\]

The labor share in manufacturing decreases in labor endowment, \( L \), and increases in income equality, \( \phi \). I will consider two different scenarios to discuss the effect of an increasing wage rate, \( w \). First, only changing the productivity in the outside sector, \( a_s \), which leads to an increasing wage rate. Second, a neutral (proportional) increase of \( \psi \) and \( a_s \). This leaves the price of a variety, \( p \), unchanged. Holding \( \psi \) constant and only increasing the productivity in the service sector increases the share of workers in the manufacturing sector if \( \gamma > \epsilon \). In this case a higher labor productivity, \( a_s \), in the outside sector will have two effects. First, given the demand for manufactures and services, less labor is needed to produce the demanded services. Second, increasing the average income without changing the income distribution increases demands for services, which leads to a higher labor demand in the service sector. If \( \gamma > \epsilon \) the first effect dominates the second effect and increasing \( a_s \) decreases the labor share allocated to services.
and increases the labor share allocated to manufactures. In the second case, where $\psi$ and $a_s$ increase proportionally, the labor share in manufacturing will unambiguously decrease. Recall that a higher per capita income implies relative more consumption of services. If the productivity increases proportionally in both sectors the output as well increases proportionally, while the relative demand shifts to services. This implies that more workers need to be employed in the service sector.

I summaries the above findings in the following proposition:

**Proposition 1:** For non-homothetic preferences, $\epsilon, \gamma > 0$ and $\sigma > 1$, the share of labor in the manufacturing sector will be higher in a country with a more equal income distribution. A higher labor endowment, $L$, decreases the labor share of manufacturing. If GDP per capita only increases due to an increase of the productivity in the service sector, $a_s$, the labor share in manufacturing decreases, if $\gamma > \epsilon$. If GDP per capita increases due to a proportional increase of productivity in the service and manufacturing sector, the labor share in manufacturing decreases.

### 3.2.4 Bilateral trade

Let us analyse the trade flows of manufactures between two countries. Trade is subject to iceberg trade costs ($\tau \geq 1$). Foreign variables are denoted by an asterisk. The price of each (intermediate) manufactured good in a country is still given by equation (3.17) which will be the same in the two countries if the income per capita to productivity ratio and the elasticity of substitution, $\sigma$, is the same in the two countries:

$$p = \frac{\sigma}{\sigma - 1} \frac{w}{\psi}$$

and

$$p^* = \frac{\sigma}{\sigma - 1} \frac{w^*}{\psi^*}.$$

The price index of the composite manufactured good depends on the prices in the two countries and iceberg trade costs:

$$P_m = \left( np^{1-\sigma} + n^*(\tau p^*)^{1-\sigma} \right)^{\frac{1}{1-\sigma}},$$

$$P_m^* = \left( n(\tau^* p)^{1-\sigma} + n^* p^{*1-\sigma} \right)^{\frac{1}{1-\sigma}}.$$
3.2. Model

The total production of an intermediate manufactures, \( q \), in the domestic country is simply \( q = c_q + \tau q^* \) and hence the profit function is \( \pi = w \left( \frac{c_q}{(\sigma - 1)\psi} - f \right) \). Free entry ensures that all firms produce the same output \( q = (\sigma - 1)\psi f \). The labor market clearing conditions follow from equation (3.21):

\[
\begin{align*}
    n \left( f + \frac{c_q}{\psi} \right) &= L_m L \quad \Rightarrow \quad n = \frac{L_m L}{\sigma f}, \\
    n^* \left( f + \frac{c_q^*}{\psi^*} \right) &= L_m^* L^* \quad \Rightarrow \quad n^* = \frac{L_m^* L^*}{\sigma f}.
\end{align*}
\]

The numbers of firms are derived as previously, but now using the price indices from equation (3.26):

\[
\begin{align*}
    n &= \frac{L}{\sigma f} w^{-\gamma} a^\gamma \left( n p^{1-\sigma} + n^* (\tau p^*)^{1-\sigma} \right)^{\frac{\gamma}{1-\sigma}} \phi,
    \\
    n^* &= \frac{L^*}{\sigma f} w^{-\gamma} a^\gamma \left( n (\tau^* p)^{1-\sigma} + n^* p^{1-\sigma} \right)^{\frac{\gamma}{1-\sigma}} \phi^*.
\end{align*}
\]

Solving the implicit function for \( \phi \) yields

\[
\frac{1}{\zeta} \left( n^{\frac{\gamma+1}{\gamma-1}} p^{1-\sigma} + n^* n^{\frac{\gamma}{\gamma-1}} (\tau p^*)^{1-\sigma} \right)^{\frac{\gamma}{1-\sigma}} = \phi,
\]

where \( \zeta = \frac{L}{\sigma f} w^{-\gamma} a^\gamma \). Everything else equal, if \( n \) increases, then \( n^* \) has to decrease, so that \( \frac{\partial n^*}{\partial n} < 0 \). By symmetry it follows that \( \frac{\partial n}{\partial n^*} < 0 \). More firms in the domestic country imply more (international) competition, which reduces the number of foreign firms. Figure 3.2 plots the two equations in (3.28). The functions can be interpreted as best-response functions for the number of firms in each country. The intersection with the axis gives the optimal number of firms in autarky. Trade reduces the number of firms in each country, but increases the total number of available varieties in both countries. An increasing \( \phi \) (more equality) will shift the functions to the north-east, as it increases the number of domestic firms and decreases the number of foreign firms. More equality in the domestic country has a spillover effect on the production of the foreign country. In equilibrium the equations in (3.28) hold simultaneously. For simplicity I assume that both countries are symmetric in all variables but equality.
Chapter 3. Trade and Inequality

Figure 3.2: "Best-responses" for number of intermediate manufacturing firms in two countries.

Under the assumption of free trade, $\tau = 1$, the equilibrium conditions can be combined and simplified to:

$$\frac{n}{n^*} = \frac{\phi}{\phi^*}. \quad (3.30)$$

After substituting this relationship into equation (3.28), it turns out that the equilibrium number of manufacturing firms in a country depends positively on its own equality and negatively on the equality in the other country:

$$\frac{\partial n}{\partial \phi} > 0, \quad \frac{\partial n^*}{\partial \phi^*} > 0, \quad \frac{\partial n^*}{\partial \phi} < 0, \quad \text{and} \quad \frac{\partial n}{\partial \phi^*} < 0. \quad (3.31)$$

See Appendix C for more details.

Moreover, note from equation (3.29) that the optimal number of firms in the domestic and the foreign country decreases for a proportional change of manufacturing and service productivities (not considering the spill-over effects described above). If the
productivity in the manufacturing sector is constant the price for each variety increases as $a_*$ increases, and consequently the number of firms in manufacturing increases with income per capita.

The optimal number of firms is interdependent for the two countries. Average GDP per capita and within-country inequality are important to determine the structure of the economy and hence trade patterns. Without loss of generality, I focus only on the trade patterns of the domestic country. The value of exports, $X$, from the domestic country is given by the multiplication of the equilibrium number of domestic (intermediate) manufactured goods, the consumption of each variety in the foreign country and the price for (intermediate) manufacturing goods:

$$\text{Export value} = X = npc^*, \quad (3.32)$$

where $c^* = \left(\frac{pr^*}{P_m^*}\right)^{-\gamma} w^* L^* \bar{S}^*_m$ is the consumption in the foreign country of each variety produced in the domestic country. An increase in equality in the domestic country ($\phi$ increases), raises exports if

$$\frac{\partial X}{\partial \phi} > 0. \quad (3.33)$$

For free trade between two symmetric countries that differ only in their equality level, this condition holds if $\frac{\gamma}{\sigma+\gamma-1} \phi < \phi^*$. If the domestic country has a high level of equality and the foreign country is very unequal, an increase of the domestic equality reduces exports. On the other hand, if the relative inequality is small, an increase of equality in the domestic country increases exports. Similarly, we find that if $\frac{\gamma}{\sigma+\gamma-1} \phi^* < \phi$, then more equality in the foreign country increases exports of the domestic country.
Proposition 2: Consider free trade between two identical countries in terms of prices, $p = p^*$, labor productivity in manufacturing, $\psi = \psi^*$, labor productivity in the service sector, $a_s = a_s^*$, and consequently identical average incomes, $w = w^*$, labor endowment, $L = L^*$, fixed costs, $f$, elasticity of substitution, $\sigma$, as well as $\epsilon, \beta, \text{and } \gamma$, but with possibly different equality levels. If $\frac{\gamma}{\sigma+\gamma-1}\phi < \phi^*$, exports from the domestic country increase with the equality of the domestic country. If $\frac{\gamma}{\sigma+\gamma-1}\phi^* < \phi$, then exports from the domestic country increase with the equality of the foreign country.

Proof see Appendix D.

Corollary: If two trading countries are similar in their equality levels, $\frac{\gamma}{\sigma+\gamma-1} < \frac{\phi^*}{\phi} < \frac{\sigma+\gamma-1}{\gamma}$, all else equal, exports increase with equality in each of the countries.

The effects of changes in the GDP per capita are not straightforward. Again I will distinguish the two cases of technological progress. If only the productivity in the service sector increases, holding constant $\psi$, I find that in general a higher average income in the foreign country raises exports of the domestic country as the aggregate demands for manufactures are strictly increasing in average income. Increasing the domestic average income has ambiguous effects. First, the price of each variety increases which increases the total value of exports, but at the same time reduces foreign demand for domestic goods. Second, for $\gamma > \epsilon$ a higher average income raises the share of workers in the manufacturing sector, which implies more firms in the manufacturing sector and exports increase. Third, the foreign price index, $P^*_m$, increases as the price of each domestic variety increases, but it decreases with the number of domestic firms. Which effect dominates is not clear and hence there is no clear-cut prediction about the effect of an increasing (average) income in the domestic country on total exports.

For a neutral increase of service and manufacturing productivity, the price of a variety, $p$, does not change, but the labor share in manufacturing and consequently the number of firms decrease. This implies that the price index, $P_m$ increases and the foreign consumption per variety increases. Again, it is not clear if the consumption effect or the number of firms effect is stronger.
3.3 Empirical analysis

The empirical analysis of the essay consists of two parts. In the first part I use reduced-form regressions to establish empirical facts that are consistent with the model predictions. First, I investigate how increasing equality in an economy increases the share of labor allocated to manufacturing as well as the effects of an increasing GDP per capita. Second, I use an augmented gravity equation to show that more within-country equality increases bilateral trade. In the second part of the empirical section I use that the individual demand functions can be aggregated including a term that reflects the whole income distribution. Hence, all key equations of the model are a function of the income distribution, which makes the model highly suitable for empirical testing. I estimate the key parameters of the model, i.e., $\epsilon$, $\gamma$, and $\sigma$. The results indicate that the preferences are non-homothetic with non-linear Engel curves. Moreover, I use these estimates to solve a multi-country trade model. As the calibrated model fits the observed trade flows very well, I use this model for counterfactual analysis.

3.3.1 Data description

The key variable in the model is the equality measure, $\phi$. I construct the equality parameter $\phi$ using data from the World Income Inequality Database 2 (WIID2). This database might be the most comprehensive for inequality measures, but still its coverage is limited. It covers 166 countries between 1887 and 2006 and has more than 5,000 observations. If a country reported more than one measure of inequality in a year, the observation chosen for the following estimations was selected as follows. First, measures of income inequality were preferred to measures of consumption inequality. Second, inequality measures based on the greatest coverage were preferred, i.e., country-wide surveys were preferred to regional surveys. Similarly, surveys covering household inequality were preferred to surveys only using males or females. Besides common inequality measures such as the Gini coefficient, Theil index or decile income ratios, the
Chapter 3. Trade and Inequality

WIID2 data includes detailed information about the income share of each decile of the population. The equality measure, \( \phi \), is calculated using these decile income shares from the WIID2 data. For empirical convenience I define \( \phi \) as

\[
\phi = \sum_{k=1}^{K} l_k^{1-\epsilon} = \sum_{k=1}^{K} \left( \frac{N_k}{K} \frac{w_l}{N} \right)^{1-\epsilon} = K^{1-\epsilon} \sum_{k=1}^{K} \left( \frac{Y_k}{Y} \right)^{1-\epsilon},
\]

where \( Y_k \) is the total income in the \( k \)th income decile. The term \( K^{1-\epsilon} \) is constant for all countries and will be part of a constant in the estimations. I set \( \epsilon = 0.0484 \).\(^6\) The equality measure, \( \phi \), is negatively correlated with the Gini coefficient with a partial correlation coefficient of -0.98.

As further controls I use total population, real GDP and real GPD per capita from the World Bank indicators. As a measure of openness I use total trade volume relative to total GDP from the World Bank indicators. As a proxy for human capital endowment I use the average years of schooling from Barro and Lee (2013). I use the average of the political and civil rights index of the Freedom House Index to proxy political development. Labor productivity measures are from the OECD STAN database and calculated as sectoral output over sectoral employment for each country and year. The labor share in manufacturing is taken from the World Bank indicators.

I use aggregate manufacturing exports from the UN COMTRADE data accessed through WITS. Manufacturing goods are defined by the two-digit HS classification in categories 28 to 97. For distance (in kilometers) between two countries I use the CEPII values from Mayer and Zignago (2011). Table 3.1 shows the summary statistics for these variables.

3.3.2 Employment share in manufacturing

First, I establish a link between within-country equality and the labor share in manufacturing as stated in Proposition 1. From equation (3.25) we know that if \( \sigma > 1 \) an increase of within-country equality, \( \phi \), raises the labor share in the manufacturing sector. Moreover, the effect of an increasing GDP per capita depends on on the the change

\(^6\epsilon = 0.0484 \) is the result of a structural estimation. All results are robust to changes in \( \epsilon \), e.g., using \( \epsilon = 0.22 \) as estimated by Boppart (2013).
3.3. Empirical analysis

Table 3.1: Summary statistics.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Obs.</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
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<tr>
<td>Population in 1,000</td>
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<td>41036</td>
<td>145473</td>
<td>9.53</td>
<td>1311020</td>
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<td>GDP in mil. USD</td>
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<td>252798</td>
<td>979108.3</td>
<td>14.93</td>
<td>1.33e+07</td>
</tr>
<tr>
<td>GDP pc in 1,000 USD</td>
<td>1533</td>
<td>8.560</td>
<td>11.35</td>
<td>.11</td>
<td>72.96</td>
</tr>
<tr>
<td>Exports in 1,000 USD</td>
<td>9737</td>
<td>748095</td>
<td>4377642</td>
<td>0.01</td>
<td>1.53E+08</td>
</tr>
<tr>
<td>$\phi$</td>
<td>505</td>
<td>1.51</td>
<td>.042</td>
<td>1.33</td>
<td>1.57</td>
</tr>
<tr>
<td>Gini</td>
<td>708</td>
<td>38.31</td>
<td>10.68</td>
<td>19.69</td>
<td>63.70</td>
</tr>
<tr>
<td>90:50</td>
<td>505</td>
<td>2.36</td>
<td>0.64</td>
<td>1.55</td>
<td>4.45</td>
</tr>
<tr>
<td>50:10</td>
<td>505</td>
<td>3.92</td>
<td>2.27</td>
<td>1.79</td>
<td>20.76</td>
</tr>
<tr>
<td>90:10</td>
<td>505</td>
<td>10.21</td>
<td>8.77</td>
<td>2.85</td>
<td>73.89</td>
</tr>
<tr>
<td>Distance in km</td>
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<td>5787.90</td>
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<td>19054</td>
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<td>Employment manufacturing (%)</td>
<td>419</td>
<td>41.35</td>
<td>11.93</td>
<td>21</td>
<td>88.3</td>
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<tr>
<td>Trade share (%)</td>
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<td>77.45</td>
<td>42.49</td>
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<td>278.99</td>
</tr>
<tr>
<td>Service productivity</td>
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<td>15678</td>
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<tr>
<td>Manufacturing productivity</td>
<td>159</td>
<td>14108</td>
<td>7807</td>
<td>1817</td>
<td>33123</td>
</tr>
<tr>
<td>Freedom House Index</td>
<td>1533</td>
<td>4.368</td>
<td>2.012</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Schooling (years)</td>
<td>1533</td>
<td>6.568</td>
<td>2.994</td>
<td>0.108</td>
<td>13.190</td>
</tr>
</tbody>
</table>

GDP, GDP per capita, exports service productivity, and manufacturing productivity are in constant 2005 USD. 1990 - 2006. Various sources.

in labor productivity in the service sector and the manufacturing sector.

Table 3.2 shows the results for a reduced form estimation of the log share of workers in manufacturing for an unbalanced panel of 65 countries between 1990 and 2010. Column (1) presents a simple regression of within-country equality on labor share in manufacturing including country and year fixed effects. Columns (2) - (7) add additional controls such as GDP per capita, population size, average years of schooling as a proxy for human capital, openness of the economy and the Freedom House Index.

All estimates indicate that more equality has a positive impact on the labor share in manufacturing as predicted by the model. A higher GDP per capita seems to have a positive impact on the labor allocation in the manufacturing sector in column (2). This results might be driven by developing countries, where an increase in GDP per capita reflects a transition from an agricultural based economy to a more industrial economy.

To control for non-monotonic effects of GDP per capita, I include the square of the log GDP per capita in columns (3) - (7). The squared term is significant and negative in columns (3) - (5), but becomes insignificant when average years of schooling is included
Table 3.2: Regression table. Employment share in manufacturing

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
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<tbody>
<tr>
<td>$\phi$</td>
<td>1.642</td>
<td>1.653</td>
<td>1.896</td>
<td>1.874</td>
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<td>1.789</td>
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<td></td>
<td>(.844)*</td>
<td>(.748)**</td>
<td>(.767)**</td>
<td>(.766)**</td>
<td>(.858)**</td>
<td>(.733)**</td>
<td>(.828)**</td>
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<tr>
<td>GDP pc</td>
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<td>.450</td>
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<td>.421</td>
<td>.356</td>
<td>.330</td>
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</tr>
<tr>
<td></td>
<td>(.023)***</td>
<td>(.190)**</td>
<td>(.195)**</td>
<td>(.191)**</td>
<td>(.190)*</td>
<td>(.192)**</td>
<td></td>
</tr>
<tr>
<td>$(GDP\ pc)^2$</td>
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<td>-.021</td>
<td>-.019</td>
<td>-.017</td>
<td>-.014</td>
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<td></td>
<td>(.011)**</td>
<td>(.011)*</td>
<td>(.011)</td>
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<td>(.091)***</td>
<td>(.095)**</td>
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<tr>
<td>Openness</td>
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<td></td>
<td>(.040)**</td>
<td></td>
<td></td>
<td>(.039)**</td>
<td></td>
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<td>FHouse</td>
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<td></td>
<td>.073</td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>(.039)*</td>
<td></td>
<td></td>
<td>(.037)**</td>
<td></td>
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</tr>
</tbody>
</table>

Robust standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

All variables in logs. 65 countries, 1990-2010. Country and year fixed effects.

as an control. GDP per capita has an inverse U-shaped effect on the labor share in manufacturing with a turning point for GDP per capita of around USD 8,000.7

The coefficients for total population, $L$, in columns (2) to (7) are negative, but not (highly) significant. This might be due to the fact that $\frac{\gamma}{1-\sigma-\gamma}$ should be small and close to zero. All results are robust for different measures for inequality, such as the Gini coefficient and decile income ratios.

### 3.3.3 Trade patterns

The previous section established a positive empirical relationship between equality and size of the manufacturing sector. If most traded goods are manufactures, a greater manufacturing sector directly implies a greater export potential. On the other hand, ev-

7In this reduced-form estimation I did not control for productivity in the manufacturing and service sector, and an increasing GDP per capita might be due to an neutral productivity increase or just to an increase in the labor productivity in the service sector. Later I will show that an increasing the productivity in the service sector leads to higher employment in manufacturing, while the reverse holds for labor productivity in the manufacturing sector.
3.3. Empirical analysis

Everything else equal, equation (3.7) indicates that economies with a more equal income distribution demand more manufactures. These two effects are captured in Proposition 2 stating that if two trading countries are similar in their equality measure, \( \phi \), increasing the equality in either of the countries increases trade. I estimate a standard gravity equation and add the equality measure, \( \phi \), for the importer and exporter.

\[
\log(X_{edt}) = \text{constant} + \alpha_1 \log(w_{et}) + \alpha_2 \log(w_{dt}) + \alpha_3 \log(L_{et}) + \alpha_4 \log(L_{dt}) \\
+ \alpha_5 \log(\phi_{et}) + \alpha_6 \log(\phi_{dt}) + \alpha_7 \log(\text{Distance}) + \xi_e + \iota_d + s_t + \omega_{adt},
\]

(3.35)

where \( X_{edt} \) are the exports from country \( e \) to country \( d \) at time \( t \) and \( \omega_{edt} \) is an error term. Table 3.3 shows the results for various specifications of the gravity equation. All estimates include importer, exporter and time fixed effects.

Column (1) presents a gravity equation using income per capita, population of importers and exporters as well as distance between exporter and importer as dependent variables.\(^8\) In column (2) the estimation includes the equality measures of the exporter and importer. More equality in the exporting country and the importing country increases the total exports of manufacturing goods. Column (3) checks for robustness, using the Gini coefficient instead of \( \phi \) for the same sample. In columns (4) and (5) I split the sample into trade between rich and poor countries, where poor countries are in the lower 25% range in terms of GDP per capita. I find that the effect of equality is only significant and positive for rich countries. An increase in the equality in poor countries is more likely to shift consumption and labor from manufacturing to agriculture, while in richer countries it would shift mainly from services to manufacturing.

In Table 3.4 I split the sample such that the exporting country has either a lower or a higher equality measure than the importing country. If \( \phi_e \leq \phi_d \), an increase of \( \phi_e \) makes two countries more equal and hence the condition from Proposition 2 is more likely to hold. In this case the model predicts that exports increase with \( \phi_e \) and conversely stay constant or decrease with \( \phi_d \), which is exactly the result of column (1). In column (2) I

\(^8\) The availability of data for \( \phi \) restricts the sample. To obtain comparable results I use the same sample in columns (1) - (3).
Table 3.3: Regression table. Log aggregate manufacturing exports.

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi_d$</td>
<td>3.934**</td>
<td>3.607*</td>
<td>1.831</td>
<td>7.429</td>
<td>1.831</td>
</tr>
<tr>
<td></td>
<td>(1.889)</td>
<td>(2.126)</td>
<td>(7.429)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\phi_e$</td>
<td>10.33***</td>
<td>6.469***</td>
<td>11.16***</td>
<td>11.16***</td>
<td>11.16***</td>
</tr>
<tr>
<td></td>
<td>(1.165)</td>
<td>(1.496)</td>
<td>(2.672)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gini$_d$</td>
<td>-.368</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(.257)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gini$_e$</td>
<td>-1.095***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(.115)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$w_d$</td>
<td>1.032***</td>
<td>1.031***</td>
<td>1.025***</td>
<td>1.164***</td>
<td>.659</td>
</tr>
<tr>
<td></td>
<td>(.115)</td>
<td>(.113)</td>
<td>(.113)</td>
<td>(.119)</td>
<td>(.435)</td>
</tr>
<tr>
<td>$w_e$</td>
<td>1.372***</td>
<td>1.249***</td>
<td>1.245***</td>
<td>1.350***</td>
<td>1.994***</td>
</tr>
<tr>
<td></td>
<td>(.0221)</td>
<td>(.0245)</td>
<td>(.0243)</td>
<td>(.0362)</td>
<td>(.159)</td>
</tr>
<tr>
<td>$L_d$</td>
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<td>-1.086</td>
<td>-1.162</td>
<td>-1.695*</td>
<td>2.668</td>
</tr>
<tr>
<td></td>
<td>(.773)</td>
<td>(.760)</td>
<td>(.767)</td>
<td>(.868)</td>
<td>(2.836)</td>
</tr>
<tr>
<td>$L_e$</td>
<td>1.245***</td>
<td>1.288***</td>
<td>1.296***</td>
<td>1.239***</td>
<td>1.545***</td>
</tr>
<tr>
<td></td>
<td>(.0212)</td>
<td>(.0222)</td>
<td>(.0228)</td>
<td>(.0273)</td>
<td>(.0493)</td>
</tr>
<tr>
<td>Dist.</td>
<td>-1.826***</td>
<td>-1.771***</td>
<td>-1.763***</td>
<td>-1.781***</td>
<td>-1.940***</td>
</tr>
<tr>
<td></td>
<td>(.0361)</td>
<td>(.0360)</td>
<td>(.0360)</td>
<td>(.0405)</td>
<td>(.0852)</td>
</tr>
<tr>
<td>$N$</td>
<td>9737</td>
<td>9737</td>
<td>9737</td>
<td>7745</td>
<td>1208</td>
</tr>
<tr>
<td>$R^2$</td>
<td>.787</td>
<td>.792</td>
<td>.793</td>
<td>.802</td>
<td>.694</td>
</tr>
</tbody>
</table>

Standard errors in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$ Aggregate exports in manufacturing, HS 28 - 97. 73 countries, 1990-2006. All variables in logs. Importer, exporter and year fixed effects.

find (weaker) opposite effects, which again squares with Proposition 2. Last, I expect that if two countries have similar levels of equality, they trade more. $\phi_e = \phi_d$ implies the highest export volume, as increasing $\phi_e$, will not (significantly) increase trade as shown in column (2) and decreasing $\phi_d$ would even reduce trade as shown in column (1). This intuition is confirmed in column (3).
3.3. Empirical analysis

Table 3.4: Regression table.

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\phi_d)</td>
<td>-2.602</td>
<td>4.114*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(4.600)</td>
<td>(2.353)</td>
<td></td>
</tr>
<tr>
<td>(\phi_e)</td>
<td>15.22***</td>
<td>3.089</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(2.126)</td>
<td>(2.445)</td>
<td></td>
</tr>
<tr>
<td>(</td>
<td>\phi_s - \phi_d</td>
<td>)</td>
<td>-0.101***</td>
</tr>
<tr>
<td></td>
<td>(.0216)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(w_d)</td>
<td>.719***</td>
<td>1.182***</td>
<td>1.036***</td>
</tr>
<tr>
<td></td>
<td>(.209)</td>
<td>(.138)</td>
<td>(.115)</td>
</tr>
<tr>
<td>(w_e)</td>
<td>1.242***</td>
<td>1.280***</td>
<td>1.371***</td>
</tr>
<tr>
<td></td>
<td>(.0388)</td>
<td>(.0298)</td>
<td>(.0221)</td>
</tr>
<tr>
<td>(L_d)</td>
<td>-2.216*</td>
<td>-3.262***</td>
<td>-1.240</td>
</tr>
<tr>
<td></td>
<td>(1.325)</td>
<td>(.812)</td>
<td>(.768)</td>
</tr>
<tr>
<td>(L_e)</td>
<td>1.309***</td>
<td>1.246***</td>
<td>1.240***</td>
</tr>
<tr>
<td></td>
<td>(.0333)</td>
<td>(.0253)</td>
<td>(.0211)</td>
</tr>
<tr>
<td>Dist.</td>
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<td>-1.758***</td>
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<td></td>
<td>(.0621)</td>
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<tr>
<td>(N)</td>
<td>4523</td>
<td>5214</td>
<td>9737</td>
</tr>
<tr>
<td>(R^2)</td>
<td>.787</td>
<td>.815</td>
<td>.788</td>
</tr>
</tbody>
</table>

Standard errors in parentheses * \(p < .10\), ** \(p < .05\), *** \(p < .01\)

Aggregated exports in manufacturing, HS 28 - 97. 73 countries, 1990-2006. All variables in logs. Importer, exporter and year fixed effects.

3.3.4 Structural estimation

The reduced form estimations clearly show the impact of equality on the sectoral allocation of labor and trade patterns. In this section I directly estimate the structural parameters of the model using the equation (3.25) for labor share in the manufacturing sector in terms of productivity in the manufacturing and service sector, total labor
endowment and the equality measure, $\phi$.

$$L_m = (sf)^{-\sigma} (L)^{-\gamma} \left( \beta \left( \frac{\sigma}{\sigma - 1} \right)^{\gamma} \right)^{\frac{1-\sigma}{1-\sigma-\gamma}} \psi^{\gamma(1-\sigma)} \phi^{1-\sigma-\gamma} a_s^{\frac{(1-\sigma)(\gamma-1)}{1-\sigma-\gamma}}. \quad (3.36)$$

To estimate the parameters $\epsilon$, $\gamma$, and $\sigma$, I write the equation in logs and estimate

$$\log(L_{net}) = \text{constant} + \frac{\gamma}{1-\sigma-\gamma} \log(L_{et}) + \frac{-\gamma(1-\sigma)}{1-\sigma-\gamma} \log(\psi_{et}) + \frac{(1-\sigma)(\gamma-\epsilon)}{1-\sigma-\gamma} \log(a_{set}) + \frac{1-\sigma}{1-\sigma-\gamma} \log(\psi_{et}) + \eta_{et}, \quad (3.37)$$

where

$$\text{constant} = \frac{-\gamma}{1-\sigma-\gamma} \log(sf) + \frac{1-\sigma}{1-\sigma-\gamma} \left( \log(\beta - \epsilon) + \gamma \log \left( \frac{\sigma}{\sigma - 1} \right) \right). \quad (3.38)$$

The subscripts $e$ indicates a country and $t$ indicates time. $\eta_{et}$ is an error term.

As as an value for $\epsilon$ is need to construct $\phi$, I use an iterative procedure (based on contraction mapping) similar to Christiano and Fisher (2000). (1) I use an arbitrary $\epsilon$ to construct $\phi$. (2) I estimate equation (3.37) using the previously constructed $\phi$. (3) I check if the obtained estimate of $\epsilon$ is close (less then $1.0E^{-6}$ difference) to the (previously) choosen $\epsilon$. (4) If not, I update the $\epsilon$ such that the new $\epsilon$ is equal to 10 percent of the estimated $\epsilon$ plus 90 percent of the initial guess. (5) I construct $\phi$ again using the new $\epsilon$. I repeat steps (2) to (5) until the estimation converges to the $\epsilon$ used to construct $\phi$. I estimate the above equation for an unbalanced panel of 25 OECD countries for the years between 1990 and 2005.\(^9\)

Table 3.5 presents the results for the structural estimation of the key parameters. Column (1) shows the estimates using OLS and column (2) includes country fixed effects. The theoretical model suggests that more equality increases the labor share in manufacturing, which is the case in both estimations. Increasing the labor productivity in

\(^9\)The estimation sample is restricted to OECD countries due to availability of labor productivity, $\psi$, in the service sector, $a_s$, and the inequality measure, $\phi$. A list of countries and years used in the estimation is in the Appendix E.
### 3.3. Empirical analysis

<table>
<thead>
<tr>
<th>Table 3.5: Structural estimation. Employment share in manufacturing.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coefficient</strong></td>
</tr>
<tr>
<td>( \log(\phi) )</td>
</tr>
<tr>
<td>( \log(\psi) )</td>
</tr>
<tr>
<td>( \log(a_s) )</td>
</tr>
<tr>
<td>( \log(L) )</td>
</tr>
<tr>
<td>Constant</td>
</tr>
<tr>
<td>( R^2 )</td>
</tr>
<tr>
<td>Obs.</td>
</tr>
</tbody>
</table>

Robust standard errors in parentheses. * \( p < .10 \), ** \( p < .05 \), *** \( p < .01 \)

The manufacturing sector (everything else equal) decreases the labor share in manufacturing, while increasing the labor productivity in the service sector increases the labor share in manufacturing. This squares with the comparative statics of equation (3.25).\(^{10}\)

Using the estimates from column (1) I obtain the estimates for the structural parameteres of the model \( \epsilon, \gamma, \) and \( \sigma \), which are 0.025, 0.026, and 4.743, respectively. The estimates for \( \gamma \) and \( \epsilon \) are small and very similar. Recall that \( \epsilon \) and \( \gamma \) equal to zero would imply a Cobb-Douglas demand structure. The elasticity of substitution, \( \sigma \), is in the range of the estimates for manufacturing trade of Broda and Weinstein (2006). The estimation in column (1) does not accout for country difference. For example, Djankov et al. (2002) note that entry costs differ largely by country which directly affects the constant term in equation (3.38). Thus, the estimation in column (1) might be misspecified. Therefore, I include country fixed effects in the preferred specification in column (2). The coefficients for equality, labor productivity in the manufacturing sector and service sec-

\(^{10}\)Labor productivity for manufactures increased by almost 3% per year from 1990 to 2005 for a typical country, while the labor productivity in the service sector did not increase significantly. This observation implies that the labor share in manufacturing should decline during this period, although the GDP per capita was not increasing significantly. This arise from the fact that the wage rate was fixed in an outside sector and hence is independent of the productivity in the manufacturing sector.
tor have the same signs as in column (1). The estimates for the structural parameters change slightly: $\epsilon$, $\gamma$, and $\sigma$ are 0.048, 0.125, and 3.66, respectively. The values of $\gamma$ and $\epsilon$ as well as their difference are greater than before, which can be interpreted as evidence for non-homotheticity. $\sigma$ is slightly lower, but still in the range of estimates of Broda and Weinstein (2006).11

3.4 Simulation

In this section I extend the model to trade between multiple countries. I use the structural estimates from the previous section to solve the model for 13 OECD countries and the corresponding trade flows. Finally, as the trade flows predicted by the model match the observed trade flows very well, I use the model for counterfactual analysis.

3.4.1 Multi-country trade

I extend the model to trade between multiple countries by adapting the price index, $P_m$ for multiple countries, so equation (3.26) becomes:

$$P_{md} = \left( \sum_e n_e (\tau_{ed} P_e) \right)^{\frac{1}{1-\sigma}}, \quad (3.39)$$

where the subscript $e$ indicates the exporter and $d$ the importer. $\tau_{ed}$ are iceberg trade costs, with $\tau_{dd} = \tau_{ee} = 1$ and $\tau_{ed} \geq 1$ if $e \neq d$. The equilibrium is defined by a system of non-linear implicit functions as in equation (3.28), but using the price index in equation (3.39). The number of firms in country $e$ depends on the number of firms all other countries. I solve this system of equations for the number of firms in 13 OECD countries in the year 2000, using the values for $\gamma$ and $\epsilon$ consistent with the fixed effects estimations of the previous section.12 The data for $\phi$ are taken from the WIID2 dataset.

11Note, that the estimates of this model are lower than the estimates of Boppart (2013) who obtained $\gamma = 0.4$ and $\epsilon = 0.22$ using data from the US consumption survey. Nevertheless, the empirical results as well as the simulation results are qualitatively robust using the estimates of Boppart (2013).

12Austria, Belgium, Czech Republic, Germany, Denmark, Finland, France, Greece, Italy, Korea, Luxembourg, Norway, Sweden, United States.
productivity measures were calculated using data from OECD STAN database. Population and GDP were taken from the World Bank Indicators. The iceberg trade costs are asymmetric and taken from Egger and Nigai (2012). Using only OECD countries for the analytical solution has three advantages. First, most of these countries were already used to estimate the parameters of the model, which makes the results more reliable. Second, trade costs between these countries are relatively small, thus they introduce less distortions to the equilibrium. Last, there aren’t any country-pairs that do not trade, hence there are no zeros in the trade matrix. Moreover, trade among these 13 countries accounts for about 43% of all trade in manufacturing goods in 2000.

Figure 3.3: Model-predicted bilateral trade vs. observed bilateral trade, aggregate manufacturing, HS 27-97. 13 OECD countries, year 2000, UN COMTRADE data. Correlation between observed and predicted trade flows is 0.83.

Figure 3.3 plots bilateral trade predicted by the theoretical model against the observed bilateral trade. The straight line in the graph corresponds to a linear regression of observable exports on predicted exports. The model explains a significant part of bilateral trade – the correlation is 0.83.


3.4.2 Trade flows and equality

As shown above the model fits the observed data qualitatively and quantitatively well, which makes it suitable for quantitative counterfactual analysis. If the equality parameter $\phi$ increases in all 13 OECD countries by 1%, bilateral trade increases in all countries on average by 0.97%. Increasing equality by 1% in the US increases exports of the US to the remaining 12 countries by about 0.9%. This implies that in equilibrium the export elasticity with respect to its own equality is close to one. Each of the remaining 12 countries increases its exports to the US by about 0.05% as a consequence of the shock. Moreover, there is a negative spillover effect on trade among the remaining 12 countries, which decreases trade between these 12 countries on average by 0.083%. The net effect on trade for the remaining 12 countries is negative, which implies that more equality in the US crowds out trade in the remaining 12 OECD countries.

3.4.3 Welfare effects

Gains from trade will not be equally distributed among income deciles. More trade leads to a lower price index of manufacturing. Poorer individuals spend relatively more on manufacturing and consequently their decile specific consumer price index decreases more than for richer individuals, which implies a greater welfare gain from trade.\textsuperscript{13} Figure 3.4 shows a whisker plot of the gains from trade after reducing trade costs to zero ($\tau = 1$) for all 13 OECD countries. Gains are the highest at the lowest decentiles and decrease with income. On average countries gain 1.66% under free trade. The correlation between average gains from trade and the equality parameter $\phi$ is 0.44, which indicates that more equal countries gain more from trade. The United States have the lowest gains from trade: on average individuals gain 0.25%. The lowest income decile in the United States gains 0.34% while the highest decile gains 0.19%. The Czech Republic gains most (2% on average). The lowest income decile in the Czech Republic gains 2.44%, while the highest decile gains 1.66%.

\textsuperscript{13}Note that these welfare gains are arising purely from the reduction of trade costs and different changes of decile specific consumer price indices. In this sense the real wage for poorer individuals increases disproportionally.
These effects differ from the results of Nigai (2013). In Nigai (2013) individuals need to consume a subsistence level of agricultural goods and start to consume tradable manufacturing goods once their income surpasses a certain threshold. If trade liberalization reduces the price of manufacturing goods, richer individuals disproportionately gain from trade. In the model in this chapter poorer individuals disproportionately consume manufacturing goods and hence gain more from trade liberalization. In this sense the results are more consistent with Khandelwal and Fajgelbaum (2013), who find that in a typical country poorer individuals gain less or lose from trade, but in high income countries, such as the United States and Japan, the reverse might be true.
3.5 Conclusion

In this chapter I presented an empirically testable framework of non-homothetic preferences, structural change and international trade considering within country inequality. In contrast to previous models that limit their analysis to two income groups this model allows for a continuous income distribution, which makes it very suitable for empirical testing. The model predicts that within country inequality and average income affect the sectoral allocation of labor into the service and the manufacturing sector. More equal economies will consume and produce relatively more manufactured goods, while economies with a higher per capita income will produce relatively more services. Trade in manufacturing goods depends on the sectoral structure of each economy and on the local demand and consequently on the income level and the income distribution in a country.

For two countries with similar levels of income equality, more equality in either of the countries increases bilateral trade. In the domestic country more equality increases the market size for manufacturing and leads to more workers and firms in the manufacturing sector. In the foreign country an increase of equality increases the market size as well and makes the country more attractive for exports. Hence, the results are driven by the non-homothetic demand structure in which within country inequality is a determinant of market size.

The predictions of the theoretical model are consistent with the empirical findings using an augmented gravity model including an equality measure. I estimate the key parameters of the model and find evidence that preferences are non-homothetic and Engel curves are non-linear. Using the structural estimates I calibrate a multi-country bilateral trade model for 13 OECD countries in the year 2000. The simulated trade flows are highly correlated with the observed ones. In a counterfactual analysis I show that if the equality in all countries increases by 1%, trade volumes increase in average by 0.97%. On the other hand, increasing equality only in the US leads to more trade of the US, while it crowds out trade between the remaining countries.
Appendix

A Engel curves

I use data from the OECD STAN Database (1990 - 2009) for 30 countries to calculate the domestic consumption of manufacturing and services. Therefore, I use total production less exports plus imports. I estimate the per capita consumption of manufacturing goods and services as a quadratic function of GDP per capita including country and year fixed effects. The per capita consumption of services increases faster than the consumption of manufacturing goods in income. Table 3.6 gives the estimation results. Figure 3.5 shows the prediction of the above estimation graphically, which reconciles

<table>
<thead>
<tr>
<th>Table 3.6: Fixed effect regression. Per capita consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>GDP pc</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>(GDP pc)$^2$</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Constant</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>$N$</td>
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</table>

Standard errors in parentheses. * $p < .10$, ** $p < .05$, *** $p < .01$

Per capita consumption of services and manufacturing in constant 2005 USD. 30 countries, 1990 - 2009. Country and year fixed effects.

with the model prediction of the PIGL preferences.

B Proof of equation (12)

\[
\frac{Y}{P_s} - \beta P_s^{r-\gamma-1} P_m^{\gamma} w^{-\epsilon} Y \phi = (1 - L_m) L a_s, \tag{3.40}
\]

use that $P_s = \frac{w}{a_s}$ and $w = y$:

\[
L a_s - \beta w^{r-1-\gamma} a_s^{1+\gamma-\epsilon} P_m^{\gamma} w^{-\epsilon} w L \phi = (1 - L_m) L a_s, \tag{3.41}
\]
Chapter 3. Trade and Inequality

Figure 3.5: Prediction of service consumption and manufacturing consumption against GDP per capita constant 2005 USD. 30 countries, 1990 - 2009.

\[ 1 - \beta w^{-\gamma} a s^{\gamma - \epsilon} P_m \phi = 1 - L_m, \]  
\[ (3.42) \]

\[ L_m = \beta w^{-\gamma} a_s^{\gamma - \epsilon} P_m \phi, \]  
\[ (3.43) \]

C Number of firms and equality

Assume complete free trade, \( \tau = 1 \), and \( p = p^* = 1 \) to simplify notation. The equilibrium condition equation (3.28) for the number of firms simplifies to

\[ n = \frac{L}{f \sigma} w^{-\gamma} \beta a_s^{\gamma - \epsilon} L^{-\epsilon} (n + n^*)^{\frac{\gamma}{\gamma - \epsilon}} \phi. \]  
\[ (3.44) \]

Substituting the equilibrium condition \( n^* = \frac{\phi^*}{\phi} n \) into the equation and solving for \( n \) yields

\[ n = \zeta^{\frac{1 - \sigma}{\gamma - \epsilon}} \left( \phi^{\frac{1 - \sigma}{\gamma}} + \phi^* \phi^{\frac{1 - \sigma - \epsilon}{\gamma}} \right)^{-\frac{\gamma}{1 - \sigma - \epsilon}}, \]  
\[ (3.45) \]
with
\[
\frac{\partial n}{\partial \phi} = \zeta \frac{1-\sigma}{1-\sigma-\gamma} \frac{\gamma}{\phi} \left( \frac{1-\sigma}{\phi} + \phi^* \frac{1-\sigma-\gamma}{\gamma} \right)^{-1} \times \left( 1 - \sigma \phi + \frac{1-\sigma-\gamma}{\gamma} \phi \phi^* \right) > 0,
\]
and
\[
\frac{\partial n}{\partial \phi^*} = \zeta \frac{1-\sigma}{1-\sigma-\gamma} \frac{\gamma}{\phi} \left( \frac{1-\sigma}{\phi} + \phi^* \frac{1-\sigma-\gamma}{\gamma} \right)^{-1} \frac{1-\sigma-\gamma}{\phi^*} < 0,
\]
for \( \sigma > 1 \) and \( 0 < \gamma < 1 \). By symmetry I find that \( \frac{\partial n}{\partial \phi^*} > 0 \) and \( \frac{\partial n^*}{\partial \phi} < 0 \). It is easy to derive the elasticities of the number of firms with respect to equality in each country,

\[
\nu_{n\phi} = \frac{\partial n}{\partial \phi}, \text{ using equations (3.46) and (3.45)}.
\]

\[
\nu_{n\phi} = \frac{\phi \gamma}{1-\sigma-\gamma} \left( \frac{1-\sigma}{\phi} + \phi^* \frac{1-\sigma-\gamma}{\gamma} \right)^{-1} \left( 1 - \sigma \phi + \frac{1-\sigma-\gamma}{\gamma} \phi \phi^* \right)
\]
\[
= \frac{\gamma}{1-\sigma-\gamma} \left( 1 + \frac{\phi^*}{\phi} \right)^{-1} \left( 1 - \sigma \phi + \frac{1-\sigma-\gamma}{\gamma} \phi \phi^* \right)
\]
\[
= \frac{\phi}{\phi + \phi^*} \left( 1 - \sigma \phi + \frac{1-\sigma-\gamma}{\gamma} \phi \phi^* \right).
\]

In a similar way I derive \( \epsilon_{n\phi^*} = \frac{\partial n^*}{\partial \phi^*} \), using equations (3.47) and (3.45).

\[
\nu_{n\phi^*} = \frac{\phi^* \gamma}{1-\sigma-\gamma} \left( \frac{1-\sigma}{\phi} + \phi^* \frac{1-\sigma-\gamma}{\gamma} \right)^{-1} \phi^* \phi^* \phi^*
\]
\[
= \frac{\phi^* \gamma}{1-\sigma-\gamma} \left( 1 + \frac{\phi^*}{\phi} \right)^{-1} \phi^*
\]
\[
= \frac{\phi^* \gamma}{1-\sigma-\gamma} \phi^*.
\]

**D Proof of export condition - equation (3.33)**

Re-stating the export equation:

\[
X = npe^*
\]
I re-write the consumption of each variety as a function of the number of firms in the two countries.

\[c^* = (p\tau^*)^{-\sigma} P_m^{\sigma-1} w^* L^* S_m = (p\tau^*)^{-\sigma} Y^* \beta P_s^{\sigma-\gamma} \phi^* (n(p\tau^*)^{1-\sigma} + n^* p^{1-\sigma})^{\frac{\sigma+\gamma-1}{1-\sigma}}, \quad (3.51)\]

where for the second equality we use equations (3.10) and (3.26). I assume two complete symmetric countries, that differ only in their inequality, and trade is complete free, \(\tau = \tau^* = 1\), the unit prices of each variety are the same in both countries, \(p = p^* = 1\). I write the exports as

\[X = \kappa^* n\phi^* (n + n^*)^{\frac{\sigma+\gamma-1}{1-\sigma}}. \quad (3.52)\]

In equilibrium for two symmetric firms I use that \(n^* = \frac{\phi^*}{\phi} n^*\):

\[X = \kappa^* n \frac{\gamma}{\sigma} \phi^* \left(1 + \frac{\phi^*}{\phi}\right)^{\frac{\sigma+\gamma-1}{1-\sigma}}. \quad (3.53)\]

To derive the condition for increasing exports, I take the derivative with respect to \(\phi\):

\[\frac{\partial X}{\partial \phi} = \phi^* \kappa^* n \frac{\gamma}{\sigma} \frac{1}{1-\sigma} \frac{\partial n}{\partial \phi} \left(1 + \frac{\phi^*}{\phi}\right)^{\frac{\sigma+\gamma-1}{1-\sigma}} + \phi^* \kappa^* n \frac{\gamma}{\sigma} \frac{1}{1-\sigma} \left(1 + \frac{\phi^*}{\phi}\right)^{-1} \frac{\phi^*}{\phi^2} > 0 \quad (3.54)\]

\[= \frac{\gamma}{1-\gamma} \frac{\partial n}{\partial \phi} \frac{1}{1-\sigma} \left(1 + \frac{\phi^*}{\phi}\right)^{-1} \frac{\phi^*}{\phi} > 0\]

\[= \epsilon_{n\phi} - \frac{\phi^*}{\phi + \phi^*} \frac{\sigma + \gamma + 1}{\gamma} < 0,\]

The condition for increasing exports is

\[\epsilon_{n\phi} < \frac{\phi^*}{\phi + \phi^*} \frac{\sigma + \gamma + 1}{\gamma}. \quad (3.55)\]
Substituting the elasticity from equation (3.48) into the above equation yields

\[
\frac{\phi}{\phi + \phi^*} \left( \frac{1 - \sigma}{1 - \sigma - \gamma} + \frac{\phi^*}{\phi} \right) < \frac{\phi^*}{\phi + \phi^*} \frac{\sigma + \gamma + 1}{\gamma}
\]

\[
\frac{1 - \sigma}{1 - \sigma - \gamma} \phi < \frac{\sigma + \gamma - 1}{\gamma} \phi^* - \phi^*
\]

\[
\frac{1 - \sigma}{1 - \sigma - \gamma} \phi < \frac{\sigma - 1}{\gamma} \phi^*
\]

\[
\frac{\gamma}{\sigma + \gamma - 1} \phi < \phi^*.
\]

(3.56)

If the equality in the domestic country increases, the LHS increases and hence the inequality will be violated at some point. This means that if the domestic country has a much higher level of equality, more equality in the domestic country will decrease the exports of the domestic country to the foreign country.

In the same way I derive the export condition for equality in the foreign country.

\[
\frac{\partial X}{\partial \phi^*} = \phi^* \kappa n \frac{\sigma + \gamma - 1}{1 - \sigma} \frac{\phi^*}{\phi} \left( 1 + \frac{\phi^*}{\phi} \right) \frac{\sigma + \gamma - 1}{1 - \sigma} - 1 \frac{1}{\phi} > 0
\]

\[
= \frac{\gamma}{1 - \sigma} \frac{\partial n}{\partial \phi^*} \frac{\sigma + \gamma - 1}{1 - \sigma} \phi^* + 1 \frac{\sigma + \gamma - 1}{1 - \sigma} \phi^* > 0
\]

\[
= \epsilon \phi^* < \frac{\sigma - 1}{\gamma} + \frac{1 - \sigma - \gamma}{\gamma} \frac{\phi^*}{\phi + \phi^*}.
\]

(3.57)

Now I substitute the elasticity from equation (3.49) into the above equation

\[
\frac{\phi^*}{1 - \sigma - \gamma \phi + \phi^*} \frac{\gamma}{\sigma + \gamma - 1} \phi^* < \frac{\sigma - 1}{\gamma} + \frac{1 - \sigma - \gamma}{\gamma} \frac{\phi^*}{\phi + \phi^*}
\]

(3.58)

which yields the symmetric condition for \( \phi^* \).

Exports increase with equality, \( \phi \), if the initial equality levels in the two countries similar.
Chapter 3. Trade and Inequality

E Country list structural estimation

<table>
<thead>
<tr>
<th>Country</th>
<th>Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>1994 - 2001</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>1996</td>
</tr>
<tr>
<td>Denmark</td>
<td>1992, 1997 - 2002</td>
</tr>
<tr>
<td>France</td>
<td>1994 - 2001</td>
</tr>
<tr>
<td>Germany</td>
<td>1992 - 2004</td>
</tr>
<tr>
<td>Greece</td>
<td>1995 - 2001</td>
</tr>
<tr>
<td>Hungary</td>
<td>1993 - 2003</td>
</tr>
<tr>
<td>Ireland</td>
<td>1994 - 2001</td>
</tr>
<tr>
<td>Isreal</td>
<td>2001</td>
</tr>
<tr>
<td>Norway</td>
<td>1991, 1995</td>
</tr>
<tr>
<td>Poland</td>
<td>1994 - 2003</td>
</tr>
<tr>
<td>Portugal</td>
<td>1998 - 2001</td>
</tr>
<tr>
<td>Slovenia</td>
<td>1996 - 1997, 1999</td>
</tr>
<tr>
<td>Spain</td>
<td>1990, 1995 - 2003</td>
</tr>
<tr>
<td>Switzerland</td>
<td>1992</td>
</tr>
</tbody>
</table>

List of countries and years used to estimate the labor share in the manufacturing sector.


4. The Effects of Trade and Endogenous Technological Change on the College Wage Gap and Unemployment

4.1 Introduction

A large literature documents a rise of wage differentials by education, by occupation, by age, and by experience groups in the United States since the late 1970s. While the college wage gap increased since the 1980s, the unemployment rate declined during the same period. These two developments coincide with an increase of the share of skilled workers in the population, technological progress as well as trade volume of the United States, see Figures 4.1 and 4.2. The two most prominent explanations for the rising college wage gap are skill-biased technological change (SBTC) and trade liberalization. In the 1990s the SBTC explanation was dominant, especially due to the analysis of Katz and Murphy (1992) and later by Autor et al. (2008). Autor et al. (2008) found the puzzling fact that since the 1960s the supply of skilled workers has increased steadily in the United States and at the same time the wage gap increased as well. Considering only the supply-side effect we would expect a decreasing wage gap. From this they conclude that the productivity of high-skilled workers increased strongly.

1Throughout this chapter the notion wage gap refers to the relative wage of workers with at least a college degree (high-skilled) and workers with only a high school diploma (low-skilled), $w_H/w_L$. 
and outweighed the negative supply-side effect. Their analysis led to many studies quantifying skill-biased technological change, especially in the form of information technology (IT), see Krueger (1993) and Jorgenson (2001). Still, Card and DiNardo (2002) critically remarked that, whenever the changes in the relative wages are not fully explained by changes in the relative skill supply, it is claimed that skill-biased technological change has caused the opposing wage development. Hence, SBTC is a residual explanation for the increasing wage gap which is hard to quantify empirically.

On the other hand, the strong increase of international trade suggests that trade has an important contribution to the increasing inequality in the United States. Autor et al. (2013) find that the strong increase of trade with China since the 1990s negatively affected the labor market outcomes of workers in the manufacturing sector in form of lower wages and lower employment rates. Trade theory would suggest such negative outcomes if countries with very different endowments of (high- and low-skilled) labor or comparative advantages trade. Most of trading partners of the United States in the 1980s were developed countries, being very similar in their industry structure to the

Figure 4.1: College wage gap (Autor, Katz and Kearny, 2008) and skill-ratio - supply of workers with at least a college degree relative to the supply of workers without a college degree (US Census Bureau, Current Population Survey, 2010).
4.1. Introduction

Figure 4.2: Trade volume (WTO Statistical Database, 2010) and unemployment rate (U.S. Bureau of Labor Statistics, 2010).

United States. Especially in the public opinion the trade liberalization with Japan in the 1980s was seen as a major factor for rising wage inequality in the United States, but standard trade theory models have difficulties to provide an explanation for the increasing inequality between two similar countries such as the United States and Japan, see the review of Kurokawa (2012). Heckscher-Ohlin trade models rely on changes in the relative price of high-skilled and low-skilled intensive goods to explain changes in the relative wage of high-skilled and low-skilled workers (Stolper-Samuelson theorem). Lawrence and Slaughter (1993) found a small decline of the relative price of high- and low-skill-intensive goods while Sachs and Shatz (1996) found that the relative price increased slightly after trade opening in the 1980s. They concluded that trade liberalization cannot explain the increasing wage gap as the relative price change was too small. Moore and Ranjan (2005) used changes in the unemployment rates of high-skilled and low-skilled workers to distinguish trade and SBTC effects on the wage gap. They found that both trade liberalization and SBTC increased the wage gap, but only SBTC was consistent with the decreasing unemployment rates of high- and low-skilled workers.
Most researchers viewed trade liberalization and skill-biased technological change as two exogenous and unrelated explanation for the increasing wage gap in the United States. Acemoglu (1998), Dinopoulos and Segerstrom (1999), and Acemoglu (2003) allow trade to have an effect on technology. Still these models were not able to explain the simultaneous increase of inequality in two trading countries as found, for example, by Verhoogen (2008) for Mexico and the United States.

I develop a model that combines trade-induced technological change and imperfect labor markets based on the concepts of Acemoglu (2003) and Moore and Ranjan (2005). The proposed model is consistent with empirical findings and hence is more robust to common criticism of trade explanations. First, the model suggests that the wage gap in the United States increased due to a disproportional increase of the wage of high-skilled workers. Second, the model indicates that the unemployment rates for high- and low-skilled workers declined after trade liberalization. Third, inequality rises simultaneously in two trading countries in response to trade liberalization. Lastly, the relative price of high- and low-skilled intensive goods does not need to change dramatically in order to explain the increasing wage gap.

As in Acemoglu (2003) research and development (R&D) firms respond to changes in market size and the price of high- and low-skilled intensive intermediate goods. Trade liberalization increases the demand for intermediate goods and hence the incentives to innovate, which induces technological progress. Search frictions in the labor market break the direct link between marginal productivity and wages. Trade-induced technological change does not only change relative productivity, but also the labor market tightness and hence the unemployment rates. In contrast to Acemoglu (2003) I allow for changes in the relative price, but skill-biased technological change will have only a small price effect, as the imperfect labor markets absorb some of the price

\[2\]A recent strand of literature analyses the effects of international trade and labor market imperfections, but this literature focuses on between firm wage differentials of ex ante homogenous workers, see Egger and Kreickemeier (2009), Helpman et al. (2010), Felbermayr et al. (2011a), Felbermayr et al. (2011b), and Egger et al. (2011). This essay is more concerned with wage differentials between different types of workers (high-skilled vs. low-skilled workers) working in different sectors (high- and low-skill-intensive sectors).
effect. This means that trade liberalization is associated with smaller price changes and hence reconciles better with the evidence found by Lawrence and Slaughter (1993) and Sachs and Shatz (1996). In contrast to Moore and Ranjan (2005), trade does not only have a price effect, but it increases the (absolute) productivity levels of high- and low-skilled workers. As in Pissarides and Vallanti (2007), productivity growth leads to a higher job creation and hence to lower unemployment rates. Allowing trade to affect technology can be an explanation for the increasing wage gap and decreasing unemployment rates of high- and low-skilled workers. Furthermore, the model permits to consider different scenarios of intellectual property rights (IPR). R&D firms react differently if two trading countries respect intellectual property rights or if one country immitates the technology of the other country. In the first case we have a market size and a price effect, that leads to increasing wage gaps in the two trading countries and to decreasing unemployment rates. In the second case, the wage gap still increases, but the unemployment rate of the low-skilled workers increases in the country that is skill-abundant. In this sense the model refines the results of Moore and Ranjan (2005).

I calibrate the model to match the United States unemployment rate and wage gap and analyse the effect of trade liberalization with Japan in the 1980s. I find that complete free trade between Japan and the United States in the 1980s would have increased the wage gap in the United States by about 14%, while the relative price of high-skilled relative to low-skilled intensive goods would have increased only by 4%.

The remainder of the chapter is organized as follows. Section 4.2 describes the basic model. The equilibrium is discussed in detail in Section 4.3. Section 4.4 introduces international trade. Section 4.5 presents some numerical solutions. Finally, Section 4.6 discusses the main findings and concludes.
4.2 Model

4.2.1 Production

The model involves high- and low-skilled individuals. All individuals have equal lifetime preferences that depend on their consumption of a final good $c$. The utility function is given by

$$u^j = \int_{\tau=0}^{\infty} c_j^\tau \exp^{-\rho \tau} d\tau \quad \text{for } j = D, F,$$

where $\rho$ is the discount factor, $\tau$ is a time index and $j = D, F$ refers to one of the two countries, Domestic or Foreign. Indices will be omitted whenever it does not lead to any confusion. In each period the final good $c$ is produced by a constant-elasticity of substitution (CES) technology using a high-skill-intensive intermediate good, $c_h$, and a low-skill-intensive intermediate good, $c_l$, so that

$$c = \left( \omega c_h^{\epsilon-1} + (1 - \omega)c_l^{\epsilon-1} \right)^{\frac{1}{\epsilon-1}},$$

where $\epsilon$ defines the elasticity of substitution between the two goods and $\omega$ is a share parameter. The subscript $i = h, l$ indicates high- and low-skilled-specific variables. Labor is not necessary for production of the final good. In each country the two intermediate goods are produced separately by a high- and a low-skill-intensive (representative) firm using the corresponding kind of local labor, $N_h$ and $N_l$, and technology, $A_h$ and $A_l$, respectively. Each intermediate good uses its own specific factor (machines), $x$, which is complementary to the sector-specific labor, i.e., skill-intensive machines can only be used by high-skilled workers and similarly for the low-skill-intensive sector. The intermediate good firm decides about the optimal machine and labor usage and takes prices and technologies as given. Intermediate goods are produced with a Cobb-Douglas production function with labor-augmenting technology

$$y_i = A_i^\beta x_i^{1-\beta} N_i^\beta \quad \text{for } i = h, l,$$
4.2 Model

where $\beta \in (0, 1)$ is a common technology parameter. $N_i$ gives the high- and low-skilled labor employed in the corresponding sector, which is different from total $i$-type labor supply, $\overline{N}_i$. Employed labor is given by $N_i = (1 - u_i)\overline{N}_i$, where $u_i$ is the sector- and skill-type-specific unemployment rate.

4.2.2 Prices

With competitive intermediate goods markets the relative price, $\overline{p} = p_h/p_l$, is determined by equation (4.2). In the optimum, the marginal rate of substitution between the two intermediate goods has to be equal to the relative price, such that

$$p = \frac{p_h}{p_l} = \left(\frac{\partial c}{\partial c_l}\right)^{-1} = \frac{1 - \omega}{\omega} \left(\frac{c_h}{c_l}\right)^{-\frac{1}{\epsilon}}. \quad (4.4)$$

The price of the final consumption good, $p_c$, depends on the prices of both inputs. For a CES production function the price is given by

$$p_c = (\omega^\epsilon p_l^{1-\epsilon} + (1 - \omega)^\epsilon p_h^{1-\epsilon})^{\frac{1}{1-\epsilon}}. \quad (4.5)$$

The real prices of intermediate goods, $\overline{p}_i$, in terms of the relative price are derived using the above expression for the final good price

$$\overline{p}_h = \frac{p_h}{p_c} = \frac{\overline{p}}{(\omega^\epsilon + (1 - \omega)^\epsilon p_h^{1-\epsilon})^{\frac{1}{1-\epsilon}}} \quad \text{and} \quad \overline{p}_l = \frac{p_l}{p_c} = \frac{1}{(\omega^\epsilon + (1 - \omega)^\epsilon p_h^{1-\epsilon})^{\frac{1}{1-\epsilon}}}. \quad (4.6)$$

The price of the high-skill-intensive good increases with the relative price while the price of the low-skill-intensive good decreases, $\frac{\partial \overline{p}_h}{\partial \overline{p}} > 0$ and $\frac{\partial \overline{p}_l}{\partial \overline{p}} < 0$.

4.2.3 Machine demand and R&D

High- and low-skill-intensive R&D firms produce and rent $h$-type and $l$-type machines as a monopolist. Intermediate good firms rent the machines in each period. Profits of
Chapter 4. Wage Gap, Inequality and Unemployment

the R&D are invested in research for new technologies. The skill-specific technology is embedded in the machine. When an intermediate good firm rents a machine, it produces with the corresponding technology level. For simplicity, only the newest vintage can be rented.\(^3\)

The intermediate good firms take the rental price, \(\chi_i\), and the technology level of the machines as given and maximize their profits with respect to machine usage, \(x_i\).\(^4\)

\[
\begin{align*}
\text{maximize } & \quad \pi_i = y_i \bar{p}_i - \chi_i x_i - N_i w_i \\
\text{subject to } & \quad y_i = A_i^\beta x_i^{1-\beta} N_i^\beta,
\end{align*}
\]

Wages and capital costs are in final good prices. This yields machine demand as a function of the rental price, the real intermediate good price, the technology level and the employed labor:

\[
x_i = \left( \frac{(1 - \beta) \bar{p}_i}{\chi_i} \right)^{\frac{1}{\beta}} A_i N_i.
\]

The machines are produced by the R&D firm that will gain monopoly rents. As the demand is iso-elastic, the common expression of the Lerner index is used to determine the optimal monopoly mark-up of the firm:

\[
\frac{1}{\epsilon_{x_i}} = \frac{\chi_i - MC}{\chi_i} \Rightarrow \beta = \frac{\chi_i - (1 - \beta)^2}{\chi_i}.
\]

The elasticity of demand is \(\epsilon_{x_i} = -\frac{1}{\beta}\). The R&D firm’s marginal costs (MC) are constant and fixed to \((1 - \beta)^2\), hence the monopoly price for each type of machine is constant at

\[
\chi_i = (1 - \beta).
\]

\(^3\)Otherwise firms would like to rent older machines after a drop of technology, as these machines are more productive. This assumption excludes this possibility.

\(^4\)Labor demand is not derived at this point as search frictions exist. Hence, the firm considers \(N_i\) as the given employment level at this point. The optimal employment level will be determined later within the search model.
4.2. Model

Replace the monopoly price, \( \chi_i \), in equation (4.8) to obtain machine demand of an intermediate producer as

\[
x_i = p_i^{\frac{1}{\beta}} A_i N_i. \tag{4.10}
\]

Machine demand increases with the employed labor, the intermediate good price and the technology level. Substituting the demand in the intermediate good production function yields

\[
y_i = p_i^{\frac{1-\beta}{\beta}} A_i N_i \quad \text{for } i = h, l. \tag{4.11}
\]

R&D firms invest profits in research, which determines the technology level, \( A_i \). The technology production function for each R&D firm is given by

\[
A_i = z_i^{\mu} q_i^{1-\mu}, \tag{4.12}
\]

where \( z_i \) is the research effort in final good units, \( q_i > 0 \) is a scale parameter and \( \mu \in (0, 1) \) is a production coefficient. Technology production has diminishing returns to research effort and hence higher levels of technology are more costly to achieve.

R&D firms make zero profits after considering the constant mark-up price from equation (4.9) and the demand function in equation (4.10).\(^5\) On the other hand, R&D firms take the intermediate good price and the employment level as given. The zero-profit condition is given by

\[
\pi_i^{RD} = 0 \rightarrow \chi_i x_i - MC x_i - z_i \beta (1 - \beta) = \beta (1 - \beta) p_i^{\frac{1}{\beta}} A_i N_i - z_i \mu \beta (1 - \beta) = 0,
\]

where \( A_i = z_i^{\mu} q_i^{1-\mu} \) and research effort costs, \( z_i \), are scaled by the expression \( \beta (1 - \beta) \) to simplify notation.

\(^5\)Unless the R&D firm does not invest all its profits into research it is profitable for another R&D firm to enter with a slightly better technology. The zero profit assumption implies monopolistic competition in the R&D sector.
The optimal research effort is
\[ z_i = q_i \left( p_i \frac{1}{N_i} \right)^{\frac{1}{1-\mu}}, \] (4.13)
which implies a technology level of
\[ A_i = q_i \left( p_i \right)^{\frac{\mu}{1-\mu}}. \] (4.14)

The higher is the intermediate good price, the more profitable is the production of the intermediate good firm and, hence, the higher is factor demand for machines and workers. Higher machine demand increases the profits of R&D firms and the technology level. For a country in autarky, the consumption of high- and low-skill-intensive goods equals the local production. Considering the technology level, the relative price can be written as a function of the labor supply ratio:
\[ p = \left( \frac{1 - \omega}{\omega} \right)^{-\epsilon} \left( \frac{y_h}{y_l} \right)^{-\frac{1}{\beta}} = \left( \frac{1 - \omega}{\omega} \right)^{-\epsilon} p^{1-\beta} A_i N_i \left( A_i N_i \right)^{-1} \]
\[ = \left( \frac{1 - \omega}{\omega} \right)^{-\epsilon} \frac{1}{p^{1-\beta}} \left( \frac{q_h}{q_l} \right) \left( \frac{N_h}{N_l} \right)^{\frac{1}{1-\mu}} \] (4.15)

Solving for \( p \) yields
\[ p = \left( \frac{1 - \omega}{\omega} \right)^{-\epsilon} \left( \frac{q_h}{q_l} \right) \left( \frac{N_h}{N_l} \right)^{\frac{1}{1-\mu}} \left( \frac{1}{1-\beta} \right)^{\frac{\beta}{(1-\beta)(1+\beta)+\mu}}. \] (4.16)

A higher employment in the skill intensive sector increases the supply of skill intensive intermediate goods and, hence, reduces its price.

### 4.2.4 Labor markets

This section introduces a search model along the lines of Pissarides (2000). The model allows to determine wages and unemployment rates in each sector. Firms will only create a vacant position if it is profitable. Workers will only accept a job offer if the wage paid is higher than their reservation wage. Exogenous shocks destroy filled positions. Unemployment exists as it takes time for the firm and the worker to form a match.
I explicitly derive all equations in Appendix A. I use two symmetric matching functions for the high- and low-skill-intensive sector.

\[ M(v_iN_i; u_iN_i) = kv_i^\gamma u_i^{1-\gamma}N_i = k\theta_i^\gamma u_iN_i \quad \text{for } i = h, l. \] (4.17)

\[ \theta_i = \frac{v_i}{u_i} \text{ reflects the labor market tightness, where } v_i \text{ is the vacancy rate and } u_i \text{ is the unemployment rate in sector } i, \gamma \in (0, 1) \text{ is a matching coefficient and } k \text{ is a scale parameter. Following Pissarides (2000), the equilibrium unemployment rate is determined as} \]

\[ u_i = \frac{\psi}{\psi + k\theta_i^\gamma}, \]

(4.18)

where \( \psi \) is the exogenous job destruction rate.

### 4.2.4.1 Firms

For the wage determination, firms consider the value of a filled and a vacant position. \( F_i \) represents the discounted value of a vacancy in a firm and \( J_i \) the present discounted value of a filled position in a firm. A vacant position is an asset for the firm. If capital markets are perfect, the valuation of this asset will be \( \rho F_i \) and equal to the expected gains from filling a position less the recruitment costs, \( \delta \): \( k\theta_i^{\gamma-1}(J_i - F_i) - \delta \). Note that \( k\theta_i^{\gamma-1} \) is the probability of filling a vacancy, \( J - F \) are the flow profits of a filled vacancy, and \( \delta \) are the initial costs of creating a vacancy or recruitment costs. In equilibrium,

\[ \rho F_i = k\theta_i^{\gamma-1}(J_i - F_i) - \delta. \] (4.19)

Similarly, a filled position has a value for the firm, which is equal to marginal profits of an additionally employed worker plus discounted expected profits until the match is resolved. The instantaneous marginal profits are calculated by subtracting the wage, \( w_i \), and the marginal costs of machines, \( r_i \), from the marginal revenues gained from employing a worker, \( t_i \). I derive the marginal revenues from employing a worker using the profit maximization problem of each intermediate good producer, see equation (4.7).
The intermediate producer takes the technology level and prices as given, so that marginal revenues can be derived using equation (4.11):

\[ t_i = \left( \frac{\partial y_i}{\partial N_i} \right) \bar{p}_i = \frac{1}{\bar{p}_i} A_i. \] (4.20)

The capital costs are calculated as \( \chi_i x_i \) using equations (4.9) and (4.10), hence the marginal rental costs are

\[ r_i = \frac{\partial (\chi_i x_i)}{\partial N_i} = \frac{1}{\bar{p}_i} A_i (1 - \beta). \] (4.21)

I can write the value of a filled position as

\[ \rho J_i = t_i - w_i - r_i + \psi (F_i - J_i), \] (4.22)

where the right-hand side are instantaneous profits of an additional employed worker, \( t_i - w_i - r_i \), plus the expected profits from the match in the future, \( \psi (F_i - J_i) \), where \( \psi \) is the exogenous job destruction rate. If \( \psi = 0 \), no unemployment exists in the model and equation (4.22) would simplify to \( \rho J_i = t_i - w_i - r_i \). Then the value of an additionally filled position, \( J_i \), would be zero and the above equation would correspond to the first-order condition with respect to labor in the firm’s maximization problem in expression (4.7). The value of a vacancy has to be zero in equilibrium, \( F_i = 0 \), otherwise firms would like to create more or less vacancies and the unemployment rate would not be in its steady state. I use the fact that \( F_i = 0 \) to combine (4.19) and (4.22) to obtain the following free-entry condition:

\[ k \theta_i^{-1} (t_i - r_i - w_i) = k \theta_i^{-1} (\beta \bar{p}_i A_i - w_i) = \delta (\psi + \rho), \] (4.23)

where I have substituted equations (4.20) and (4.21) in equation (4.22) to receive the second equality.

### 4.2.4.2 Workers

Workers accept any job that pays a higher wage than their reservation wage. The present-discounted value of being unemployed is equal to the social benefits, \( b \), plus
the expected gain from finding a job. On the other hand, the present-discounted value of being employed is equal to the wage plus the expected loss when a match is destroyed. These considerations lead to the following two standard Bellman equations in the Pissarides model.

\[
\rho U_i = b + k_\theta i (W_i - U_i), \tag{4.24}
\]

\[
\rho W_i = w_i + \psi (U_i - W_i), \tag{4.25}
\]

where \( U_i \) is the present discounted value of unemployment and \( W_i \) is the present discounted value of employment. The worker receives social benefits, \( b \), if unemployed. \( k_\theta i \) gives the rate at which workers find a job (and \( \psi \) the rate at which workers lose their job). Note that all exogenous parameters, such as recruitment costs, \( \delta \), or social benefits, \( b \), and scale parameter, \( k \), are the same for high- and low-skilled workers and firms. Different values of the exogenous parameters for the high- and low-skill-intensive sector do not change the qualitative results of the model. For example, higher recruitment costs for high-skilled workers increase the high-skilled unemployment rate and reduces the high-skilled wages and consequently the wage gap. This is aligned with the behavior of unemployment and wages in search unemployment models. Nevertheless, this analysis focuses less on the labor market institutions, but rather on the interaction of trade, labor markets, and technological progress. See Weiss and Garloff (2009) for a detailed analysis of the behavior of SBTC and unemployment with different institutions in detail.

### 4.2.4.3 Wage Bargaining

Wages are determined by Nash-bargaining over the profits of a filled position:

\[
w_i = \arg \max (W_i - U_i)^\eta (J_i - F_i)^{1-\eta}. \tag{4.26}
\]

The parameter \( \eta \) defines the bargaining power of workers and firms. A higher \( \eta \) gives more weight to the workers and \( \eta = 0.5 \) implies symmetric bargaining. The first-order
condition for equation (4.26) is

\[ W_i - U_i = \frac{\eta}{1 - \eta} (J_i - F_i). \] (4.27)

From this expression, the wage equation can be derived analogously to Pissarides (2000):\(^6\)

\[ w_i = (1 - \eta)b + \eta(\beta p_i^{1/\beta} A_i + \delta \theta_i). \] (4.28)

Combining equation (4.28) and the free entry condition (4.23) obtains an implicit function of the labor market tightness, \( \theta_i \):

\[ (1 - \eta)[\beta p_i^{1/\beta} A_i - b] - \eta \delta \theta_i - \frac{\delta(\rho + \psi)}{k\theta_i^{\gamma-1}} = 0. \] (4.29)

The labor market tightness is a key variable as it defines the equilibrium of the model. Equation (4.29) gives the equilibrium condition for each sector in the model. After substituting equations (4.6), (4.4), and (4.14) the labor market tightness is a function of labor supply. The relative price depends on the labor market tightness of both sectors, thus the implicit functions in equation (4.29) have to hold simultaneously for both sectors. Once the labor market tightness for each sector is determined for a given labor supply, all other variables can be determined.

### 4.3 Equilibrium

For a country in autarky the equilibrium is defined by

\[ (1 - \eta)[\beta p_i^{1/\beta} A_i - b] - \eta \delta \theta_i - \frac{\delta(\rho + \psi)}{k\theta_i^{\gamma-1}} = 0 \quad \text{for} \quad i = h, l, \] (4.30)

where

\[ \beta = \left( \frac{1 - \omega}{\omega} \right)^{-\epsilon} \left( q_h \right) \left( q_l \right) \left( \frac{(1 - u_h)N_h}{(1 - u_l)N_l} \right)^{1/\epsilon} - \frac{\beta(1 - \mu)}{(1 - \mu)(\beta + (1 - \beta)) + \mu}, \]

\(^6\)The complete mathematical derivation is shown in the Appendix A.
4.3. Equilibrium

\[
\bar{p}_h = \frac{p}{(\omega^e + (1 - \omega)\bar{p}^{1-\epsilon})^{\frac{1}{1-\epsilon}}},
\]
\[
\bar{p}_l = \frac{1}{(\omega^e + (1 - \omega)\bar{p}^{1-\epsilon})^{\frac{1}{1-\epsilon}}},
\]
\[
A_i = q_i(\bar{p}_i^{\frac{\beta}{2}} (1 - u_i)N_i)^{1-\nu},
\]
\[
u_i = \frac{\psi}{\psi + k\theta_i^e}.
\]

Although the system has no closed-form solution, comparative statics help to understand the mechanics of the model. Consider the prices and technology levels as exogenous, the labor market tightness is an increasing function of technology, \(A_i\), and the real intermediate good prices, \(\bar{p}_i\).

\[
\frac{\partial \theta_i}{\partial A_i} > 0 \quad \frac{\partial \theta_i}{\partial \bar{p}_i} > 0.
\]

By equation (4.18) a higher \(\theta_i\) reduces the unemployment rate. Thus, higher intermediate good prices and technological progress reduce unemployment, as both factors make employment of more workers more profitable for an intermediate producer.

**Proposition 1:** For a given \(\theta_l\) (\(\theta_h\)), an increase in the labor supply \(N_h\) (\(N_l\)), will raise the labor market tightness \(\theta_h\) (\(\theta_l\)) and reduce the unemployment rate \(u_h\) (\(u_l\)).

Assume that the labor market tightness of the other sector is constant, then the labor market tightness of each sector is increasing with its labor supply. This implies that the unemployment rate in each sector is a decreasing function of the respective labor supply, since

\[
\frac{\partial \theta_i}{\partial N_i} > 0 \quad i = h, l.
\]

The decreasing unemployment rate is driven by the increasing technology, which can be interpreted as a "capitalization" effect, i.e., recruitment costs become less and less important and new matches are formed easier. This is consistent with the empirical evidence for a negative relationship between the unemployment rate and labor productivity, see Pissarides and Vallanti (2007). A high-skilled labor supply shock will have two
opposing effects on the technology level. First, it reduces the relative price by increasing
the production of the high-skill-intensive goods. A decreasing intermediate good price
will diminish the profit incentives of the high-skilled complementary R&D firm, which will
lead to a lower technology level. On the other hand, the demand for high-skilled ma-
chines will increase as more high-skilled workers are employed. This in turn increases
the profits of the high-skilled complementary R&D firm and the technology level. The
net effect of the negative price change and the positive labor market size effect on the
relative technology level can be evaluated by using equation (4.14) and replacing the
relative price by equation (4.16).

\[ \frac{A_h}{A_l} = \left( \frac{q_h}{q_l} \right) \left( \frac{1}{p^{\beta} N_h/N_l} \right)^{\frac{\mu}{1-\mu}} = \kappa \left( \frac{q_h}{q_l} \right) \left( \frac{(1-u_h)N_h}{(1-u_l)N_l} \right)^{\frac{\mu}{1-\mu}} \left( \frac{p^{\beta(1-\epsilon)}}{(1-\mu)(\epsilon^{\beta+1}-\mu)} \right), \]

(4.31)

where \( \kappa = \left( \frac{1-\omega}{\omega} \right)^{-\epsilon} \left( \frac{q_h}{q_l} \right)^{1-\mu} \left( \frac{-1}{(1-\mu)(\epsilon^{\beta+1}-\mu)} \right) \). The relative technology increases in \( N_h \)
and decreases in \( N_l \) for given unemployment rates if \( \epsilon > 1 \). Hence, technological
change will be skill-biased if the skill-ratio increases.

**Proposition 2:** For a given labor market tightness in the two sectors, an increase in
the labor supply \( N_h (N_l) \) raises (reduces) the relative technology if \( \epsilon > 1 \). An increasing
skill-ratio implies skill-biased technological change.

The wage in each sector depends on the sectoral technology level, the intermediate
good price and the labor market tightness, as can be seen from equation (4.28). An
increase in the skill supply will have a positive impact on the labor market tightness and
the technology, but at the same time the intermediate good price will decline. Which
effect dominates is not clear a priori.

### 4.4 International Trade

Assume that trade occurs only in intermediate goods between two countries. Trade in
intermediate goods equalizes the relative prices in the two economies. As all individuals
have the same preferences and face the same prices after trade-opening, they have the same relative demand of high- and low-skill-intensive goods. Hence, the post-trade relative price, $p^T$, satisfies

$$p^T = \frac{p_h}{p_l} = \frac{1 - \omega}{\omega} \left( \frac{y_D^h + y_F^h}{y_D^l + y_F^l} \right)^{\frac{1}{\mu}},$$

where the post-trade prices for high- and low-skill-intensive goods are still given by equation (4.6) when using the above post-trade relative price. Intellectual property rights (IPRs) are crucial in the model. I distinguish two cases. First, intellectual property rights are only enforced in the domestic country and not in the foreign country. This implies that R&D activities only take place in the domestic country and the foreign country copies the technology and machines developed domestically. This case can be interpreted as trade with technology imitation. In the second case, IPRs are enforced in the foreign country after trade-opening. As the R&D firm has a monopoly, only one R&D firm for each sector rents machines to intermediate good firms in both countries.  

### 4.4.1 Technology imitation - IPR violation

Assume that the foreign developing country is a developing economy, without research sector, and copies the existing technology and machines of the developed domestic country. Consequently, the domestic R&D sector does not take into account the machine demand of the foreign country. The technology in both countries will be given by equation (4.14), but the domestic R&D firm considers the post-trade price. Trade liberalization with an imitating country has a price effect but no market-size effect for technology:

$$A^T_i = q_i (p^T_i)^{\frac{N^D_i}{\mu}}.$$

Proposition 2 still holds after trade liberalization, i.e., if the skill-ratio in the domestic country increases, technological progress is skill-biased, and

---

7The superscript $T$ indicates specific trade variables.

8As the technology and machines are produced without labor, it does not matter in which country the R&D firm is located. Once IPR are enforced in the two countries, only one R&D firm has the cutting edge patents and hence will cover all the demand for machines.
Chapter 4. Wage Gap, Inequality and Unemployment

\[
\frac{A^T_h}{A^T_l} = \left( \frac{q_h}{q_l} \right) \left( \frac{p^T}{p} \right)^{1 - \mu} \left( \frac{1 - u_h N_h}{1 - u_l N_l} \right) \frac{\mu}{1 - \mu}. \tag{4.34}
\]

Trade liberalization induces skill-biased technological change if the skill-ratio of the domestic country is higher than that of the foreign country. To see this, substitute the post-trade technology level from equation (4.33) in the production function of the domestic and foreign countries. Considering the relationship for the relative price, \(p^T\), as given in equation (4.32) and using that trade in intermediate goods equalizes the prices in the two economies, the relative world market price is a function of the labor supply of the two trading countries:

\[
p^T = \left( \frac{1}{\omega} \right)^{-\epsilon} \left( \frac{1 - \omega}{\omega} \right)^{1 + \beta (1 - \rho) + \mu} \left( \frac{q_h}{q_l} \right) \left( \frac{N_D h N_D l}{N_L} \right)^{1 - \mu} \left( \frac{1 + N_F^D}{1 + N_F^L} \right)^{\frac{1}{2} - \epsilon} \left( \frac{1 + N_F^D}{1 + N_F^L} \right)^{\frac{1}{2} - \epsilon}. \tag{4.35}
\]

Solving the above equation for \(p^T\) yields an analogous expression to equation (4.16):

\[
p^T = \kappa^{\frac{1}{2}} \left( \frac{N_D h N_D l}{N_L} \right)^{\frac{\mu}{1 - \mu}} \left( \frac{N_D h + N_F^D}{N_D l + N_F^L} \right)^{\frac{\beta (1 - \rho)}{1 + \beta (1 - \rho) + \mu}}. \tag{4.36}
\]

The relative price will increase in the domestic country if it starts trading with a country that is scarcer in high-skilled labor, i.e., \(\frac{N_D h}{N_D l} > \frac{N_F^D}{N_F^L}\). The post-trade relative price increase will be greater, the higher is the difference between the skill-ratios of the two countries. Trade liberalization with an imitating country with a lower skill-ratio leads to an increasing domestic wage gap. First, the price for high-skill-intensive goods increases and the price for low skill intensive goods decreases. Second, technological progress is biased towards skilled workers. Both effects work in favor of high-skilled workers.

**Proposition 3:** For given high- and low-skilled unemployment rates trade-opening to a country with a lower skill-ratio that does not respect IPR will increase the domestic relative price and induce domestic skill-biased technological change. The domestic wage gap will increase in response.
4.4. International Trade

The technology level and the relative price are changing after trade liberalization with an imitating country, the expression for the labor market tightness has to be adapted. The post-trade relative price depends on the employment levels in both countries and hence the implicit functions for the labor market tightness for the two sectors in the two countries have to be satisfied simultaneously in equilibrium:

\[(1 - \eta)[\beta \bar{p}_i^T (\frac{1}{\beta} A_i^T - b) - \eta \delta \theta_i^T - \frac{\delta(p + \psi)}{k(\theta_i^T)\gamma - 1}] = 0 \quad \text{for} \ j = D, F \ \text{and for} \ i = h, l, \quad (4.37)\]

where \(\bar{p}_i^T\) is given by equation (4.6) substituting the relative world market price \(p^F\). The expression for the unemployment rate, \(u_i\), is unchanged and given by equation (4.18). The labor market tightness has to be the same in both countries after trade liberalization as all exogenous parameters in the matching function, the prices, and the technology levels are the same everywhere.

4.4.2 No technology imitation - IPR enforcement

Trading under IPR enforcement is very similar to a labor-supply shock. The domestic R&D firm considers the demand of foreign intermediate good firms for machines. In this setting trade-opening implies that only one R&D firm exists in both countries which considers the demand of both countries for machines. The zero profit condition is given by

\[\pi_i^{RD} = 0 \quad \rightarrow \quad \chi_i(x_i^D + x_i^F) - MC(x_i^D + x_i^F) - z_i\beta(1 - \beta) = 0,\]

where \(A_i = z_i q_i^{1-\mu}\).

Since the technology levels and prices are the same in both countries after trade liberalization, the above equality yields the technology level after trade liberalization with an IPR-respecting country:

\[A_i^T = q_i (p_i^T (N_i^D + N_i^F))^{\mu} = q_i (p_i^T ((1 - u_i^D)N_i^D + (1 - u_i^F)N_i^F))^{\mu}. \quad (4.38)\]

The expression for the technology level has to be substituted in the equilibrium condition in equation (4.37), which again has to hold for the two sectors in both countries. A special and simple case is noteworthy. If the foreign IPR-enforcing country and the
domestic country are completely symmetric, trade-opening will not change the relative price for given unemployment rates and only a market-size effect for technology can be observed. The market-size effect will be different from the effect in Acemoglu (2003) as changes in technology will change the labor market tightness and hence unemployment rates and wages will change.

4.5 Numerical results

The equilibrium conditions for the basic model and the trade model, equation (4.30) and (4.37), respectively, have no closed-form solution, but they can be solved numerically. I present three different scenarios. First, I consider a country in autarky with a changing skill-ratio. Second, I show the effects of trade liberalization with a country that respects IPR. Finally, I investigate the effects of trade liberalization with an IPR-violating country.

4.5.1 Calibration

I calibrate the model to match the wage gap and unemployment rate of the economy of the United States. The values for the exogenous variables presented in Table 4.1 are in line with the values taken by Pissarides (2007, 2009). For the supply of high-skilled and low-skilled workers, I use data from the US Census of Population Educational Attainment from 1963 to 2003, where skilled workers are defined as to have at least a college degree. The skill-ratio increases because the supply of high-skilled workers increases faster than the supply of low-skilled workers. The literature suggests an elasticity of substitution in final good production function of $\epsilon \approx 1.5$, see Hamermesh and Grant (1979), Krusell et al. (2000), Katz and Murphy (1992), Autor et al. (2008) or Epifani and Gancia (2008).

A key parameter is the elasticity of substitution, $\epsilon$, in the production function of the final good. I solve the model alternatively for $\epsilon$ between 1 and 3 and discuss the effects when needed. The parameter $b$ for social benefits and the recruitments costs $\delta$ have to be sufficiently low relative to the wage to ensure a solution. A higher technology production coefficient $\mu$ increases the spread between pre- and post-trade wage levels.
4.5. Numerical results

Table 4.1: Model calibration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta$</td>
<td>0.66</td>
<td>Cobb-Douglas production coefficient</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>0.5</td>
<td>Matching parameter</td>
</tr>
<tr>
<td>$\delta$</td>
<td>$\in (0.1,1)$</td>
<td>Recruitment costs</td>
</tr>
<tr>
<td>$\epsilon$</td>
<td>$\in (1, 3)$</td>
<td>Elasticity of substitution for the final good production</td>
</tr>
<tr>
<td>$\eta$</td>
<td>0.5</td>
<td>Bargaining power parameter</td>
</tr>
<tr>
<td>$\mu$</td>
<td>$\in (0.25,0.6)$</td>
<td>Technology production parameter</td>
</tr>
<tr>
<td>$\rho$</td>
<td>0.004</td>
<td>Discount factor</td>
</tr>
<tr>
<td>$\psi$</td>
<td>0.019</td>
<td>Job destruction rate</td>
</tr>
<tr>
<td>$b$</td>
<td>free</td>
<td>Social benefits</td>
</tr>
<tr>
<td>$k$</td>
<td>free</td>
<td>Unemployment scale parameter</td>
</tr>
<tr>
<td>$q_h$</td>
<td>free</td>
<td>Skilled technology scale parameter</td>
</tr>
<tr>
<td>$q_l$</td>
<td>free</td>
<td>Low skilled technology scale parameter</td>
</tr>
</tbody>
</table>

Parameter values following Pissarides (2007, 2009).

The technology scale parameter $q_i$ is set to 3.5 for the high- and low-skilled technology to give a reasonable wage gap. As all exogenous parameters determining the labor market tightness are the same for the two countries and the post-trade prices and technology levels are the same, also the labor market tightness has to be the same in both countries after trade liberalization. This condition makes the numerical results stable to changes in the starting values for the algorithm.

4.5.2 United States in autarky

In this section I show the results for wages, unemployment rates and technology of both skill groups for a country in autarky. The change in the labor supply of the United States increased the skill-ratio from 0.09 to 0.37 between 1963 and 2003. Figure 4.3 presents the associated consequences in the calibrated model graphically. The wage gap declines for elasticities of substitution in the interval $(1, 2.5)$. For higher values of $\epsilon$ the wage gap increases. Different to Acemoglu (2003) and Moore and Ranjan (2005) an $\epsilon$ in excess of 2.5 is needed to explain a slight increase of the wage gap.\(^9\) Still, the increasing skill-ratio will lead to skill-biased technological progress for any $\epsilon > 1$. The model is able to consider the stock of high- and low-skilled workers, separately.

\(^9\)For all other simulations I use $\epsilon = 1.5$, which is the common estimate for the parameter.
4.5.3 Trade of the United States with Japan

The case of trade between the United States and a foreign IPR-respecting country, taking Japan as an example, is shown in Figure 4.4. The supply of low-skilled workers is 70% of the supply in the domestic country (United States) and the supply of skilled
workers is 60% of the United States supply. The lower relative labor supply ensures that the relative price increases after trade liberalization. The values for the foreign country are chosen to match the skill supply and the size of the Japanese population in the 1985 census. At $t = 20$ the two countries start trading. In response to that, in the domestic country the wage gap increases significantly, unemployment rates decline and wages increase for both skill groups. Two points are very important. First, the wage inequality rises because the wages of high-skilled workers increase faster than those of the low-skilled workers. Second, the unemployment rates for both skill groups decrease after trade-opening. This illustrates that trade liberalization can increase the wage gap and reduce the unemployment rate of low-skilled workers at the same time. Note that the number of vacancies is a forward looking variable, it adapts immediately to trade opening. This leads to the big jump at $t = 20$ in Figure 4.4, where countries switch from autarky to free trade by assumption. If the two countries opened only gradually, the transition would be smoother. The here presented numerical result can be seen as evidence that increasing trade of the United States, especially with developed countries such as Japan, in the 1980s contributed to the development of the wage gap.

**Figure 4.4:** Numerical solution for the domestic country trading with smaller developed country that respects IPR, for example Japan. $\epsilon = 1.5$. 

seen as evidence that increasing trade of the United States, especially with developed countries such as Japan, in the 1980s contributed to the development of the wage gap.
in the United States. In this setup a relatively small price change is able to explain a significant increase of the wage gap: the relative price increases by less than 4% while the average wage gap increases by about 14%. These results are consistent with the empirical findings of Lawrence and Slaughter (1993) and Sachs and Shatz (1996). The results are very similar for the foreign country as all exogenous parameters are the same. This implies that in the foreign country (Japan) the wage gap increases as well. Figure 4.5 shows the results graphically. In contrast to the domestic case, the relative technology increases as the domestic country has a higher skill-ratio. Also decreasing unemployment rates for high- and low-skilled workers can be observed in this case. If I allow trade to not only alter the relative technology but as well the absolute technology level, bilateral trade can consistently explain the increase of wage inequality in the two trading countries.

Figure 4.5: Numerical solution for the foreign country that respects IPR trading with bigger developed country. $\epsilon = 1.5$. 
4.5.4 Trade with a technology-imitating country

Figure 4.6 summarizes the numerical results for trade with a technology-imitating foreign country. The supply of high-skilled workers in the foreign country is only 25% of the supply in the domestic country and 50% for low-skilled workers, taking Mexico as an example. This implies that the price change is considerably greater than in the case of trade with a developed country. Trade liberalization leads to an increasing wage gap and skill-biased technological change in the domestic country. The high-skilled unemployment rate declines while the low-skilled unemployment rate increases. This behavior is consistent with the findings of Moore and Ranjan (2005) who use the increasing unemployment rate of low-skilled workers to identify the effect of trade on the wage gap. Similar to Moore and Ranjan (2005), trade causes the wages of the low-skilled workers to decrease and the wages of the high-skilled workers to increase.

![Graphs showing wage gap, relative technical change, and unemployment rates over time for high-skilled and low-skilled workers.](image)

Figure 4.6: Numerical solution for the domestic country trading with a small developing country (no IPR) with a low skill-ratio. $\epsilon = 1.5$
4.6 Conclusion

In this chapter I analyse the wage gap in the United States and its relationship with unemployment rates of high- and low-skilled workers in the context of trade liberalization and endogenous technological change. I emphasize the importance of absolute technological change due to trade liberalization. Search frictions in the labor market break the direct link between productivity and wages and diminish the impact of trade on relative prices. A higher supply of a certain type of workers increases the employment of workers of this skill type. This increases the demand for machines which are complementary to this worker type and increases the research effort in R&D to develop the complementary technology. Thus, an increasing skill-ratio, due to a higher supply of high-skilled workers, always leads to skill-biased technological change. The higher technology levels make employment more profitable and reduce unemployment rates. This can be interpreted as a common capitalization effect in search unemployment models. For a country in autarky, the wage gap increases with an increasing skill-ratio only if the elasticity of substitution between intermediate goods in the production of the final good is sufficiently high.

The numerical results in this chapter suggest that for the labor supply of the United States an elasticity of substitution of at least 2.5 is needed to ensure an increasing wage gap in response to an increasing skill-ratio. Trade liberalization with a country that respects intellectual property rights (such as Japan) is consistent with the observed patterns of wages and unemployment rates in the United States in the 1980s. First, the wage gap increases due to a disproportional increase of high-skilled wages. This squares with the empirical findings of Autor et al. (2008). Second, unemployment rates for both skill types decline. Third, during the period of trade liberalization in the 1980s inequality increases globally. Lastly, the model predicts that the wage gap increases in both trading countries after trade liberalization, while the associated changes in the relative price are small. This fact is consistent with the empirical findings of Lawrence and Slaughter (1993) and Sachs and Shatz (1996).

On the other hand, the model suggests that the findings of Moore and Ranjan (2005) only hold for trade with a country that imitates technology. I calibrate the domestic
country to match the United States in the 1980s and show that trade opening to other
developed countries, such as Japan, can explain an increasing wage gap and decreasing unemployment rates for both skill groups in both countries. The model predicts that free trade with Japan in the 1980s would have increased the wage gap in the United States by roughly 14%, at the same time the relative price increased only by 4%. 
Appendix

A Proof search unemployment

This section derives the explicit equations for the search model used in Section 4.2.4.

Matching functions

\[ M(v_i N_i; u_i N_i) = kv_i^{\gamma_i} u_i^{1-\gamma_i} N_i = k\theta_i^{\gamma_i} u_i N_i \quad \text{for } i = h, l. \]  

(4.39)

The labor market tightness, \( \theta_i \), is the ratio of vacancies to unemployed workers, \( \frac{v_i}{u_i} \). The rate at which a worker finds a job is defined as

\[ M(v_i N_i; u_i N_i) u_i N_i = k\theta_i^{\gamma_i} \quad \text{for } i = h, l, \]  

(4.40)

which is increasing in the labor market tightness. The rate at which a vacant position is filled is given by

\[ M(v_i N_i; u_i N_i) v_i N_i = k\theta_i^{\gamma_i-1} \quad \text{for } i = h, l, \]  

(4.41)

which is decreasing in the labor market tightness. The flow rate into unemployment per unit of time, \( \dot{u}_i \), is given as the rate of exogenously destroyed matches less the rate of workers newly employed.

\[ \dot{u}_i = \psi (1 - u_i) - k\theta_i^{\gamma_i} u_i \quad \text{for } i = h, l, \]  

(4.42)

where the parameter \( \psi \) reflects an exogenous break up rate for filled positions. In the equilibrium, \( \dot{u}_i = 0 \) will be satisfied. This gives the steady state unemployment rate:

\[ u_i = \frac{\psi}{\psi + k\theta_i^{\gamma_i}} \quad \text{for } i = h, l. \]  

(4.43)

A vacant position is an asset for the firm. If capital markets are perfect, the capital costs \( \rho F_i \) have to be equal to the rate of return on assets. The latter is given as the expected gains from filling a position less the recruitment costs, The expected gains are calculated using the marginal revenues, \( t_i \), and subtract the (marginal) rental costs,
\( r_i \) and the wage \( w_i \).

\[
\rho F_i = k\theta_i^{-1}(J_i - F_i) - \delta \tag{4.44}
\]

\[
\rho J_i = t_i - w_i - r_i + \psi(F_i - J_i) \tag{4.45}
\]

Similarly, a filled position has a capital cost of \( \rho J_i \) to the firm. This has to be equal to the current marginal revenues of a worker less the wage and the (marginal) rental costs of machines less the expected loss if the match is destroyed at some point in time. In equilibrium, all profit opportunities from new jobs are exploited, driving rents from a vacant position to zero. Therefore, the equilibrium condition for the supply of vacant jobs is zero. Given a non-zero discount factor \( \rho \), this is satisfied if \( F_i = 0 \). This implies that firms can enter and exit the market freely, and

\[
J_i = \frac{t_i - w_i - r_i}{\rho + \psi}. \tag{4.46}
\]

After substituting \( J_i \) from equation (4.44) the above equation can be written as

\[
k\theta_i^{-1}(t_i - w_i - r_i) = \delta(\psi + \rho). \tag{4.47}
\]

Workers face a similar problem as firms. \( U_i \) is the present discounted value of unemployment and \( W_i \) is the present discounted value of employment. Workers receive social benefits \( b \) if unemployed. \( k\theta_i \) gives the rate at which workers are employed and \( \psi \) the rate at which workers lose their job. These considerations lead to the following two Bellman equations:

\[
\rho U_i = b + k\theta_i(W_i - U_i), \tag{4.48}
\]

\[
\rho W_i = w_i + \psi(U_i - W_i). \tag{4.49}
\]

Note that the permanent income \( W_i \) is different from the actual wage rate \( w_i \). This is caused by the risk of unemployment and hence a lower income. It is assumed that the wage will be higher than social benefits, i.e., \( w_i > b \), so that an incentive to work exists.
Solving the above equation for \( W_i \) yields
\[
W_i = w_i + \psi U_i, \tag{4.50}
\]

To derive the wage as given in equation (4.28) a common Nash-bargaining model is used by way of which
\[
w_i = \arg \max (W_i - U_i)^\eta (J_i - F_i)^{1-\eta}. \tag{4.51}
\]
The corresponding first order condition yields
\[
W_i - U_i = \frac{\eta}{1-\eta} (J_i - F_i). \tag{4.52}
\]

First, substitute (4.46) and (4.50) in (4.52) and use \( F_i = 0 \) to obtain
\[
w_i = \rho U_i + \eta (t_i - r_i - \rho U_i). \tag{4.53}
\]

From equation (4.44) and \( F_i = 0 \) it follows that
\[
J_i = \frac{\delta}{k \theta_i^{\gamma-1}}. \tag{4.54}
\]

Replace \( J_i \) in equation (4.52) by equation (4.44) to obtain
\[
W_i - U_i = \frac{\eta}{1-\eta} \left( \frac{\delta}{k \theta_i^{\gamma-1}} \right). \tag{4.55}
\]

Now substitute equation (4.55) in (4.48) to derive
\[
\rho U_i = b + \frac{\eta}{1-\eta} \delta \theta_i. \tag{4.56}
\]

Use (4.56) with (4.53)
\[
w_i = b + \frac{\eta}{1-\eta} \delta \theta_i + \eta (t_i + r_i - b - \frac{\eta}{1-\eta} \delta \theta_i),
\]
\[
w_i = (1-\eta)b + \frac{\eta}{1-\eta} \delta \theta_i + \eta t_i - \eta r_i - \frac{\eta^2}{1-\eta} \delta \theta_i, \tag{4.57}
\]
which then simplifies to the wage equation as given by equation (4.28).

\[ w_i = (1 - \eta)b + \eta(t_i - r_i + \delta \theta_i). \]  

(4.58)

The wage depends on three endogenous parameters: marginal revenues, \( t_i \), (marginal) rental costs, \( r_i \), and labor market tightness, \( \theta_i \). Substituting the expression for the \( t_i \) and \( r_i \) from equations (4.20) and (4.21) in the equations (4.58) yields

\[ w_i = (1 - \eta)b + \eta(\beta \overline{p}_i^{1/\beta} q_i A_i + \delta \theta_i). \]  

(4.59)

\( \theta_i \) can be defined as an implicit function by using equations (4.58) and (4.47). The labor market tightness depends on marginal revenues, \( t_i \), and marginal rental costs, \( r_i \), as well:

\[ t_i - r_i - [(1 - \eta)b + \eta(t_i - r_i + \delta \theta_i)] - \frac{\delta(\rho + \psi)}{k\theta_i^{\gamma - 1}} = 0. \]  

(4.60)

After substituting \( t_i \) and \( r_i \) from equations (4.20) and (4.21), this simplifies to

\[ (1 - \eta)[\beta \overline{p}_i^{1/\beta} q_i A_i - b] - \eta \delta \theta_i - \frac{\delta(\rho + \psi)}{k\theta_i^{\gamma - 1}} = 0. \]  

(4.61)
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