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Strategic Technology Investments in Open Economies

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Anna Bohnstedt
Christian Schwarz

Strategic Technology Investments in Open Economies

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Universität Duisburg-Essen, Department of Economics
Universitätsstr. 12, 45117 Essen, Germany

Rheinisch-Westfälisches Institut für Wirtschaftsforschung (RWI)
Hohenzollernstr. 1-3, 45128 Essen, Germany

Editors

Prof. Dr. Thomas K. Bauer
RUB, Department of Economics, Empirical Economics
Phone: +49 (0) 234/3 22 83 41, e-mail: thomas.bauer@rub.de

Prof. Dr. Wolfgang Leininger
Technische Universität Dortmund, Department of Economic and Social Sciences
Economics – Microeconomics
Phone: +49 (0) 231/7 55-3297, email: W.Leininger@wiso.uni-dortmund.de

Prof. Dr. Volker Clausen
University of Duisburg-Essen, Department of Economics
International Economics
Phone: +49 (0) 201/1 83-3655, e-mail: vclausen@vwl.uni-due.de

Prof. Dr. Christoph M. Schmidt
RWI, Phone: +49 (0) 201/81 49-227, e-mail: christoph.schmidt@rwi-essen.de

Editorial Office

Joachim Schmidt
RWI, Phone: +49 (0) 201/81 49-292, e-mail: joachim.schmidt@rwi-essen.de

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Anna Bohnstedt and Christian Schwarz[1]

Strategic Technology Investments in Open Economies

Abstract

We study a general equilibrium model of international trade with heterogeneous firms, where countries can strategically invest in technology. The countries' motive is to improve firms' productivity, leading to a competitive advantage in international trade. We are interested in how trade liberalization affects this governmental incentive to invest in technology. In the closed economy countries invest if consumers have a sufficiently high preference for varieties. In the open economy we analyze the Nash-equilibrium policy and the cooperative policy. If there are no cross-country investment spillovers, countries strategically compete in their investment levels and increase their investments with higher trade openness. From a social perspective we have an overinvestment problem. If there are cross-country investment spillovers, we differentiate between weak and strong spillovers. In both cases the cooperative solution predicts a positive relationship between investments and trade openness. If there are weak (strong) spillovers, we find a positive (hump-shaped) relationship between technology investments and trade openness in the Nash-equilibrium. From a social perspective we obtain an over (under)-investment problem if spillovers are weak (strong).

JEL Classification: F12, F13

Keywords: Heterogeneous firms; technology investments; monopolistic competition; strategic trade policy

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1 *Both University of Duisburg-Essen. – Corresponding author: Anna Bohnstedt, Department of Managerial Economics, University of Duisburg-Essen, Lotharstr. 65, LB 319b, 47057 Duisburg, Germany. E-Mail: anna.bohnstedt@uni-due.de,*

1 Introduction

In a globalized world, countries strategically invest in technology to maintain competitiveness, increase efficiency, and stimulate growth. In particular investments in education, infrastructure and research and development (R&D) are supposed to improve a country's technology level. However, public expenditures related to technology improvements differ vastly across countries. Consider, for example, the teacher-per-pupils ratio as a basic proxy for educational quality.[1] Using World Bank data for the year 2006, Norway has a teacher-per-pupils ratio of one teacher to ten pupils, while Congo has a ratio of 1:83. The political debate highlights the importance of strategic technology investments in the light of falling trade barriers. The common theme is that highly integrated economies actually need better technology levels to allow their firms to keep up with foreign competition.[2]

What is not well understood in the literature, is how international trade affects the government's incentive to *strategically* invest in technology. In fact, to the best of our knowledge, there is no literature which discusses the impact of trade liberalization on a country's incentive to endogenously invest in technology. We analyze this issue in a general equilibrium model of trade with heterogeneous firms.

A framework with heterogeneous firms is a suitable basis for our analysis. This is for two reasons. First, it is a salient empirical feature that firms are heterogeneous in such dimensions as productivity, size, or export activity.[3] Second, and more importantly, it is the more realistic framework for our purposes. Technology investments raise the technological standard in a country as a whole. However, they do not necessarily improve the productivity in every single firm in this country in the same way and magnitude.[4] In our model we capture this idea by assuming a stochastic process, where firms randomly draw their productivity level from a common and known distribution. The government's technology investment is then modeled as an improvement of the support of this distribution and

[1] To substantiate the teacher-per-pupils ratio as a measure for educational quality, see the UNESCO (2006) report on Teachers and Educational Quality, p. 26: "The number and distribution of teachers are important policy parameters helping to determine the quality of education. The pupil-teacher ratio is a commonly-used indicator, reflecting the human resource capacity of education systems."

[2] See e.g. the Presidency Conclusions of the Council of the European Union (2008), p. 9: "Providing high-quality education and investing more and more efficiently in human capital and creativity throughout people's lives are crucial conditions for Europe's success in a globalized world."

[3] Empirical literature that identifies the existence of productivity heterogeneity on the firm level is e.g. Bernard and Jensen (1999), Aw et al. (2000), Clerides et al. (1998) or Bernard et al. (2003).

[4] For instance, recall a model with homogeneous firms like in Krugman (1980). The only way to model technology improvements would be investments that decrease marginal costs of all firms. This would imply that every firm benefits exactly in the same way and magnitude.

hence the investment leads to an increase of the average productivity across firms, but not necessarily to a productivity gain for each single producer.

The seminal model of an open economy with heterogeneous firms is Melitz (2003). Demidova (2008) and Falvey et al. (2005) use that framework and allow for country-specific differences in technology. They show that countries with a "superior" technology are also characterized by a higher average productivity, and exhibit welfare gains due to a lower price index. In these papers, technology differences across countries are exogenous, however, while we consider endogenous technology differences, which arise because of government investments.

Our model is based on an extension of the Melitz (2003) model provided by Pflueger and Suedekum (2009). Firms have to pay a sunk entry cost before they learn about their productivity level, which is randomly drawn from a common and known distribution. Firms with a sufficiently high productivity draw stay in the industry and start producing, and firms with a productivity below an endogenously determined cutoff level exit immediately. Trade liberalization leads to a selection effect such that only the most productive firms start exporting, firms with intermediate productivity serve the domestic market only, and the least productive firms exit.

We introduce a government that invests in technology and these investments have to be refinanced through a lump-sum tax. What is the incentive for this policy? In the closed economy, investments in technology tighten firm selection and lead to more productive firms, which sell larger quantity and charge lower prices. Thus, the increased toughness of competition has a positive welfare effect for consumers. In the open economy two aspects give countries a strategic incentive to invest in technology. Firstly, if one country invests more in technology than the other, this yields tougher competition in the leading country and softer competition in the laggard country. Secondly, exporting becomes easier for firms from the leading country, while exporters from the laggard country now face tougher competitors. Hence, technology investments in one country lead to a negative cross-country externality as they give domestic firms a competitive advantage on both markets.

In this paper, we study a setting with two countries, which strategically interact in technology investments to give their domestic firms a competitive advantage over foreign firms. Our results can be summarized as follows. In the closed economy countries have an incentive to invest if consumers have a sufficiently high preference for varieties. In the open economy we analyze the Nash-equilibrium policy and the cooperative policy that maximizes joint welfare. If there are no cross-country investment spillovers, the cooperative

solution is equivalent to the autarky solution. In the Nash-equilibrium, countries strategically compete in their investment levels and increase their investments with higher trade openness in order to take advantage of the negative cross-country externality to foreign firms. From a social perspective we have an over-investment problem. If there are cross-country investment spillovers, we differentiate between weak and strong spillovers. In both cases, the cooperative solution predicts a positive relationship between investments and trade openness. If there are weak (strong) spillovers, we find a positive (hump-shaped) relationship between investments and trade openness in the Nash-equilibrium. From a social perspective we obtain an over (under)-investment problem in the Nash-equilibrium policy if spillovers are weak (strong).

1.1 Related Literature

As mentioned above, our model is based on the seminal paper on heterogeneous firms by Melitz (2003). His work incorporates heterogeneous firms into the monopolistically competitive framework by Krugman (1980). Entry and exit of firms is modeled similarly as in Hopenhayn (1992). Besides the broad literature on heterogeneous firms, there are several strands of literature which are related to our model.

Firstly, this paper is related to the literature on technology gaps across countries, i.e., countries with different technologies. Demidova (2008) and Falvey et al. (2005) analyze technology differences in a heterogeneous firms framework, where firms draw their productivity from different exogenously given distributions. These productivity distributions are such that one country has access to a superior distribution than the other, i.e., distributions can be ranked. Thereby Demidova (2008) assumes a general functional form and Falvey et al. (2005) consider the productivity distribution to be Pareto, with differences in the support. However, no endogenous differences due to technology investments are analyzed in these papers.

Secondly, there is more recent literature on policy issues in frameworks with monopolistic competition and heterogeneous firms (see e.g. Demidova and Rodriguez-Clare (2009), Chor (2009)). From that literature, Pflueger and Suedekum (2009) is particular closely related as they consider strategic government interactions in entry subsidies. However, to our knowledge, none of these papers consider strategic technology investments.

Finally, our model is related to the large industrial organization literature on R&D spillovers. In this literature a firm's productivity is related to the own R&D spending, but it also pos-

itively depends on the R&D spending of other firms in the industry and public spending in technology. This externality to other firms is commonly called a spillover. For instance, Cohen and Levinthal (1989) define knowledge "spillovers to include any original, valuable knowledge generated in the research process which becomes publicly accessible". Studies by Adams (1990), Jaffe (1989) and Jaffe et al. (1998) examine knowledge spillovers from academic research to firms' R&D investments. These studies suggest that geographical proximity matters and that spillovers exhibit a rapid spatial decay. In our model we differentiate between spillovers within a country and spillovers across countries, which depend on the degree of trade freeness. We add to this literature by studying the impact of trade liberalization in a general equilibrium framework.

The paper is organized as follows. In section 2 the closed economy is presented. Section 3 introduces the open economy. Section 4 derives the cooperative policy and the non-cooperative Nash-equilibrium policy if there are no investment spillovers, while section 5 derives those regimes if there are spillovers across countries. Section 6 concludes and provides a brief empirical test of the model's predictions.

2 Closed Economy

Consider a single country under autarky. The economy is populated by L workers that each supply one single unit of labor, which is the only factor of production. The economy consists of two sectors: a homogeneous good sector A with constant returns to scale and a manufacturing sector C with a continuum of differentiated varieties and monopolistic competition. In the manufacturing sector C, each firm produces a unique variety under increasing returns to scale and the firms are heterogeneous in their marginal productivities.

2.1 Preferences

The preferences of a representative household h are defined over a homogeneous good A and the set of differentiated varieties Ω produced in sector C. Utility is a quasi-linear, logarithmic function with CES subutility over the consumption of varieties Ω:

$$U = \beta \ln C^h + A^h \quad \text{with} \quad C^h = \left(\int_{z \in \Omega} q^h (z)^\rho \, \mathrm{d}z \right)^{1/\rho},$$

where $0 < \rho < 1$ and $\beta > 0$. The household's consumption of a variety z is given by $q^h(z)$. The elasticity of substitution between any two varieties is given by $\sigma \equiv 1/(1-\rho)$. The CES price index is given by:

$$P = \left(\int_{z \in \Omega} p(z)^{1-\rho} \, \mathrm{d}z \right)^{1/(1-\sigma)}.$$

Utility maximization leads to per-capita expenditure for the numeraire good and the manufacturing aggregate $PC^h = \beta$ and $A^h = y^h - \beta$, respectively. To simplify notation we drop the household index h and it can be shown that indirect utility is given by:

$$V = y - \beta \ln P + \beta (\ln \beta - 1), \tag{1}$$

which is decreasing in the CES price index. Total demand for and revenue of a single variety z is denoted by $q(z) = \beta L p(z)^{-\sigma} P^{\sigma-1}$ and $r(z) = p(z) q(z) = \beta L (P/p(z))^{\sigma-1}$, respectively.

2.2 Production and Firm Behavior

Production in the homogeneous good sector A has constant returns to scale and perfect competition. One unit of labor translates into one unit of output. This good is used as the numeraire, so that the wage rate can be normalized to one. In the manufactured good sector C, varieties are produced with increasing returns to scale under monopolistic competition. Each firm produces one unique variety z. The technology in the manufacturing sector is comprised by total costs $l = f + q/\varphi$ to produce q units of output. Every firm has the same overhead production cost f but firms are heterogeneous in their marginal costs $1/\varphi$. A higher φ represents a higher productivity. Profit maximization leads to the firm-specific optimal price p, which is a constant mark-up over marginal costs:

$$p(\varphi) = \frac{\sigma}{(\sigma - 1)\varphi} = \frac{1}{\rho \varphi}. \tag{2}$$

Total demand for and revenue of a single firm can be rewritten as $q(\varphi) = \beta L (\rho\varphi)^{\sigma} P^{\sigma-1}$ and $r(\varphi) = \beta L (\rho\varphi P)^{\sigma-1}$, and operating profits are given by $\pi(\varphi) = r(\varphi)/\sigma - f$. It is evident that a firm with a higher productivity level φ charges a lower price, sells a larger quantity, and has a higher revenue as well as higher profits. The CES price index given

above can be rewritten as follows:

$$P = M^{1/(1-\sigma)} p\left(\widetilde{\varphi}\right) = M^{1/(1-\sigma)} \frac{1}{\rho \widetilde{\varphi}} \quad \text{with} \quad \widetilde{\varphi} \equiv \left[\int_0^{\infty} \varphi^{\sigma-1} \mu\left(\varphi\right) \mathrm{d}\varphi \right]^{1/(\sigma-1)}, \tag{3}$$

where M represents both the mass of manufacturing firms and varieties. The productivity distribution among active firms is $\mu\left(\varphi\right)$ and $\widetilde{\varphi}$ denotes the average productivity level.

2.3 Entry and Exit

At each point of time, there is a mass M^E of entrepreneurs that enter the manufacturing sector C. To enter the market, entrepreneurs have to pay entry costs f_e, which are thereafter sunk. After entering the industry, firms draw their productivity level from a given distribution function. In the original Melitz (2003) model the distribution of productivities among firms is unparameterized, while we assume the commonly used Pareto distribution.[5] That distribution function is given by:

$$G\left(\varphi\right) = 1 - \left(\frac{\varphi^{MIN}}{\varphi} \right)^k, \tag{4}$$

with density $g\left(\varphi\right) = k \left(\varphi^{MIN}\right)^k \varphi^{-(k+1)}$. Here $\varphi^{MIN} > 0$ is the lower bound for productivity draws and $k > 1$ is the shape parameter. After learning about their productivity, firms decide whether to start producing or to exit the market immediately. A firm with a productivity draw below some threshold level, $\varphi < \varphi^*$, decides to exit, while a firm with a productivity draw above this threshold, $\varphi > \varphi^*$, decides to stay active. Every active firm can be hit by a bad shock with a probability $\delta > 0$ at each point of time. This would force the firm to shut down and exit the market. The probability of a bad shock is independent of φ. In a stationary equilibrium without time discounting, the mass of entrants, which successfully enter the market equals the mass of firms, which are forced to shut down: $p_{IN} M^E = \delta M$, where $p_{IN} = 1 - G\left(\varphi^*\right)$ is the survival probability. The endogenous productivity distribution among active firms, $\mu\left(\varphi\right)$, is then the conditional ex-ante distribution $g\left(\varphi\right)$ on the domain $(\varphi^*, \infty]$.

[5] The Pareto distribution has been widely used in the literature on heterogeneous firms e.g. in Helpman et al. (2008), Melitz and Ottaviano (2008) or Behrens et al. (2009).

2.4 Equilibrium

As in Melitz (2003) the autarky equilibrium is characterized by two conditions linking cutoff productivity and average profits. The free entry condition (FEC) secures that entry occurs until the value of entry, $v^E = E\left[\sum_{t=0}^{\infty}(1-\delta)^t \pi(\varphi)\right] - f_e$, is driven to zero:

$$\overline{\pi} = \frac{\delta f_e}{1 - G(\varphi^*)} = \delta f_e \left(\frac{\varphi^*}{\varphi^{MIN}}\right)^k. \tag{FEC}$$

The zero cutoff profit condition (ZCPC) pins down the revenue of the cutoff firm, $r(\varphi^*) = \sigma f$, which by using $r(\widetilde{\varphi})/r(\varphi^*) = (\widetilde{\varphi}/\varphi^*)^{\sigma-1}$ and $\overline{\pi} = r(\widetilde{\varphi})/\sigma - f$ leads to:

$$\overline{\pi} = f\left[\left(\frac{\widetilde{\varphi}}{\varphi^*}\right)^{\sigma-1} - 1\right] = \frac{f(\sigma-1)}{k+1-\sigma}, \tag{ZCPC}$$

with $k > \sigma + 1$. As figure 1 illustrates, there exist an unique equilibrium level for φ^* and $\overline{\pi}$.[6] Solving for the equilibrium value of φ^* leads to the autarky cutoff productivity φ^*_{AUT} given by:

$$\varphi^*_{AUT} = \left(\frac{f(\sigma-1)}{\delta(k+1-\sigma)f_e}\right)^{1/k} \varphi^{MIN}. \tag{5}$$

Furthermore, the equilibrium mass of surviving firms, M, and the equilibrium mass of entrants, M^E, can be derived. Given that the aggregate consumption expenditure for varieties, βL, must equal the aggregate revenue of surviving firms, $R = M\overline{r} = Mr(\widetilde{\varphi})$, and solving for M yields $M = \beta L/\overline{r}$, where $\overline{r} = \sigma(\overline{\pi} + f)$. Moreover, the market clearing condition for the A-sector requires that the value of consumption equals the value of production, $(1 - t - \beta)L = (1 - \gamma)L$, where γ denotes the share of the workforce employed in the manufacturing sector. Solving for the manufacturing workforce yields $\gamma = \beta + t$ and indicates that higher taxes increase the manufacturing share in the economy. This is because lump-sum taxes only reduce the consumption of the numeraire good. The mass of surviving firms is then given by $M = \beta L/\sigma(\overline{\pi} + f) = (\gamma - t)L/\sigma(\overline{\pi} + f)$ and the mass of entrants follows from $M^E = \delta M/(1 - G(\varphi^*_{AUT}))$. In the stationary equilibrium the mass of surviving firms and entrants is then given by:

$$M_{AUT} = \left(\frac{k+1-\sigma}{\sigma k f}\right)\beta L \quad \text{and} \quad M^E_{AUT} = \left(\frac{\sigma-1}{\sigma k f_e}\right)\beta L. \tag{6}$$

[6] The ZCPC is unaffected by the minimum productivity parameter φ^{MIN} and a horizontal in (φ, π)-space, which is an outcome of the assumed Pareto distribution.

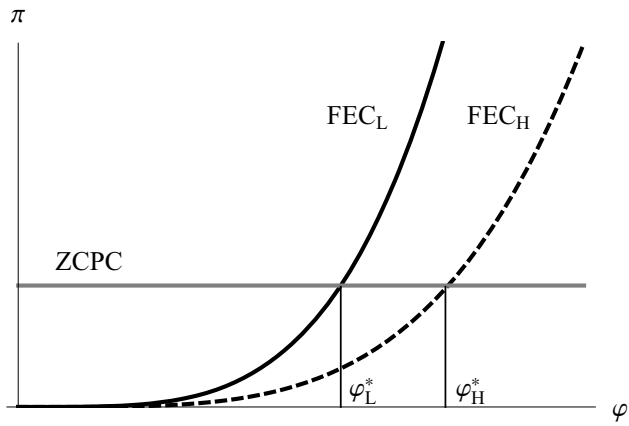

Figure 1: FEC and ZCPC

Finally, indirect utility can be rewritten as follows:

$$V_{AUT} = y + \beta \ln \varphi^*_{AUT} + \frac{\beta}{\sigma - 1} \ln L + \kappa_1, \tag{7}$$

where $\kappa_1 = \beta \left(\ln \left(\beta \rho \right) - 1 \right) + \frac{\beta}{\sigma - 1} \ln \left(\beta / \sigma f \right)$ is a constant. Welfare increases in the country size L and the cutoff productivity φ^*_{AUT}. The intuition for a welfare gain due to an increase in the cutoff productivity is straightforward. A higher cutoff productivity increases the average productivity, $\widetilde{\varphi} = \left(\frac{k}{k+1-\sigma} \right)^{1/(\sigma-1)} \varphi^*_{AUT}$, which in turn decreases the CES price index and therefore leads to a welfare gain for consumers.

Moreover, with the assumed Pareto distribution the cutoff productivity φ^*_{AUT} is proportional to and increasing in the minimum productivity draw φ^{MIN}. This can also be easily seen in figure 1. Consider an increase in φ^{MIN}, which represents the lower bound of the assumed Pareto distribution. Only the FEC changes while the ZCPC is unaffected. The initial level of φ^{MIN} is depicted by the thick curve (FEC_L), while a higher level of φ^{MIN} is depicted by the dashed curve (FEC_H). With a higher φ^{MIN} the equilibrium cutoff productivity increases. If we think of the minimum productivity as a firm's worst outcome in the Melitz type lottery, it is intuitively clear that an increase in the minimum productivity (e.g. from an initial level φ^{MIN}_L to a higher level φ^{MIN}_H as depicted in figure 2) does not only raise the chance to draw a better productivity in this worst case scenario, but also in all other cases. Hence, a higher minimum productivity, as illustrated in figure 2, shifts the

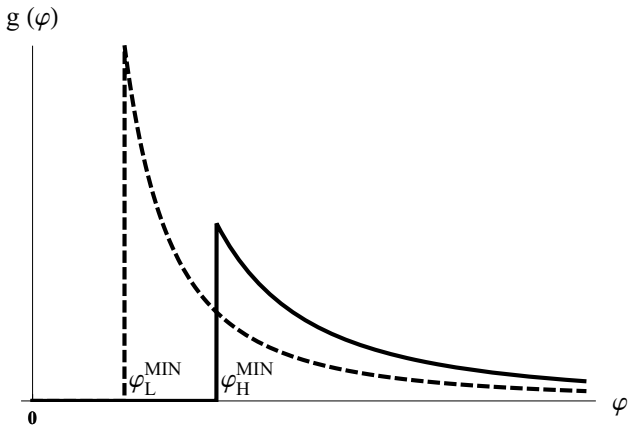

Figure 2: Pareto distribution with different lower bounds

density function to the right and the cutoff and the average productivity increase.[7]

The increased cutoff and average productivity also accounts for the fact that the market consists of higher productive firms due to tougher selection, induced by a higher minimum productivity. Although in the long run perspective of a stationary equilibrium the mass of entrants and surviving firms is independent of the minimum productivity, in the short run the masses are indeed affected. The mechanism at work can be separated into two effects: First, an increase in the minimum productivity raises a firm's probability to draw a productivity level equal or larger than a given cutoff productivity. Hence, expected profits rise and a larger value of entry induces more entry into the market. The second effect works in the opposite direction. A larger mass of entrants leads to more active firms in the market, inducing tougher competition. Increased competition lowers expected profits and decreases the value of entry, which in turn decreases the mass of entrants. Under the assumed Pareto distribution both effects are of equal magnitude and lead to masses M_{AUT} and M^E_{AUT} independent of the minimum productivity. In the end, an increase in the minimum productivity φ^{MIN} does not lead to *more* but *better* firms in the equilibrium. These better firms charge lower prices, sell larger output, and have higher revenue and profits.

[7]Note that with a higher φ^{MIN} the maximum value of the density function $\bar{g} \equiv \max g = k/\varphi^{MIN}$ decreases.

2.5 Technology Investments

In the following we consider endogenous investments in technology, which have to be re-financed by lump-sum taxes. For simplicity we normalize the country size $L = 1$. The tax rate is denoted by t, and since $w = 1$ and $L = 1$, total tax revenue is given by $T = t(wL) = t$. We assume an efficient government such that the investment level is also denoted by T. The government invests T and the technology level in the country is denoted by $H(T)$. We assume that investments in technology generate positive but decreasing marginal returns, formally:

$$H' = \frac{\partial H}{\partial T} > 0 \quad \text{and} \quad H'' = \frac{\partial H'}{\partial T} < 0. \tag{8}$$

In the case of zero investments the technology level is zero, i.e. $H(0) = 0$. The minimum productivity draw φ^{MIN} is a function of the technology level H and given by:[8]

$$\varphi^{MIN} = \exp\{H(T)\}. \tag{9}$$

Note that we normalized the minimum productivity level in case of no investments. In the following we refer to the properties of H with respect to T (positive but decreasing marginal returns) and silently assume that φ^{MIN} features the same. To see this consider the following technical note.

Technical Note: Investments T have the same properties with respect to H and φ^{MIN} if we assume the "mild" condition $(H')^2 < -H''$. Proof:

$$\varphi^{MIN\prime} = \frac{\partial \varphi^{MIN}}{\partial T} = H'\varphi^{MIN} > 0 \quad \text{and} \quad \varphi^{MIN\prime\prime} = \frac{\partial \varphi^{MIN\prime}}{\partial T} = \varphi^{MIN}\left[(H')^2 + H''\right] < 0.$$

Hence, a higher H also mirrors a higher minimum productivity φ^{MIN} and we have positive but decreasing marginal returns of investment T.
Welfare in the closed economy case is given by:

$$V = 1 - T + \beta \ln \varphi^*_{AUT} + \frac{\beta}{\sigma - 1} \ln L + \kappa_1 = 1 - T + \beta \ln \varphi^{MIN} + \kappa_2, \tag{10}$$

[8] Our specification of φ^{MIN} leads to closed form solutions and allows for a variety of other related functional forms. Our results do not depend on the given exponential specification.

where $\kappa_2 = \kappa_1 + \frac{\beta}{\sigma-1}\ln L + \frac{\beta}{k}\ln\left(\frac{f(\sigma-1)}{\delta f_e(k+1-\sigma)}\right)$ is a constant.[9] The necessary condition for a welfare optimum is the first-order condition (FOC) given by:

$$\frac{\partial V}{\partial T} = -1 + \beta\frac{\varphi^{MIN\prime}}{\varphi^{MIN}} = -1 + \beta H' = 0. \tag{11}$$

From the FOC we can clearly disentangle the different effects of higher investments in technology. Investments T rise the lump-sum tax which has a negative marginal unit welfare burden. However, they also increase the minimum productivity, rising the cutoff and average productivity, decreasing the price index, and at the end increasing welfare at the margin by $\beta H'$. Comparative statics can be derived by the implicit function theorem. Define $\zeta \equiv H' - 1/\beta$ and we have:

$$\frac{\partial T}{\partial \beta} = -\frac{\partial \zeta}{\partial \beta}\left(\frac{\partial \zeta}{T}\right)^{-1} = -\frac{1}{\beta^2 H''} > 0. \tag{12}$$

Result 1: Under autarky countries have an incentive to invest in technology if $\beta H' > 1$ for any $0 < T < 1$. It is more likely that countries invest in technology if consumers have a high preference β for varieties.[10]

3 Open Economy

The open economy consists of two countries $i = 1, 2$ that are identical in the country size ($L = 1$) but may potentially differ in technology. We discriminate between technologies by allowing for country-specific differences in the lower bound of the assumed Pareto distribution, as in Falvey et al. (2005). These differences are due to different levels of investments in technology. Ultimately we are interested in the endogenous determination of the investment policy. This will be analyzed in great detail in sections 4 and 5 below. For now, in section 3, we first analyze the international equilibrium when the technology differences are exogenously given.

[9] It is furthermore worth mentioning that the consumer's choice among consumed varieties is unaffected since the mass of surviving firms is independent of the minimum productivity.

[10] To illustrate result 1 consider the following example: Let $H = \sqrt{T}$. Then we have $H' = 1/\left(2\sqrt{T}\right)$. Solving $H' = 1/\beta$ for the optimal tax rate leads to $T^* = \beta^2/4$. The assumption $(H')^2 < -H''$ of our technical note also holds.

3.1 Equilibrium in the Open Economy

Production of varieties in sector C still encompasses both variable and fixed costs as in the closed economy case. There are additional fixed costs of exporting, f_x, if a firm decides to serve the foreign market. Moreover, we assume standard iceberg-type trade costs, i.e. one unit of output to arrive needs $\tau > 1$ units of output to be shipped. Trade in the A-sector is costless, which ensures factor price equalization provided both sectors are active in both countries. The FEC remains unchanged for country i compared to the closed economy and is given by:

$$\overline{\pi}_i = \delta f_e \left(\frac{\varphi_i^*}{\varphi_i^{MIN}} \right)^k. \tag{FEC}$$

The ZCPC changes in the open economy due to the fact that firms can engage in exporting. Expected profits in country i are now given by $\overline{\pi} = \pi_i(\widetilde{\varphi}_i) + p_{xi}\pi_{xi}(\widetilde{\varphi}_{xi})$, where $\widetilde{\varphi}_i$ is the average productivity among all domestic active firms and $\widetilde{\varphi}_{xi}$ is the average productivity across exporting firms from country i.[11] Furthermore the probability to export is given by $p_{xi} = (\varphi_i^*/\varphi_{xi}^*)^k$. Using $\widetilde{\varphi}_i/\varphi_i^* = \widetilde{\varphi}_{xi}/\varphi_{xi}^* = \left(\frac{k}{k+1-\sigma}\right)^{1/(\sigma-1)}$, the ZCPC can be written as follows:

$$\overline{\pi}_i = \frac{f(\sigma-1)}{k+1-\sigma} \left[1 + \phi \left(\frac{\varphi_i^*}{\varphi_j^*} \right)^k \right], \tag{ZCPC}$$

where $\phi \equiv \tau^{-k} (f/f_x)^{\frac{k+1-\sigma}{\sigma-1}}$ is a measure of trade openness. We assume $f_x \geq f$, which implies $0 < \phi < 1$. A higher ϕ indicates a higher freeness of trade. Substituting the FEC into ZCPC leads to a system of two equations in the two cutoffs, which in turn determines the cutoff productivities in the open economy:

$$\varphi_1^* = \left[\frac{\chi(1-\phi^2)}{\chi - \phi} \right]^{\frac{1}{k}} \left[\frac{f(\sigma-1)}{\delta f_e (k+1-\sigma)} \right]^{\frac{1}{k}} \varphi_1^{MIN} \tag{13}$$

and

$$\varphi_2^* = \left[\frac{1-\phi^2}{1-\phi\chi} \right]^{\frac{1}{k}} \left[\frac{f(\sigma-1)}{\delta f_e (k+1-\sigma)} \right]^{\frac{1}{k}} \varphi_2^{MIN}, \tag{14}$$

where $\chi = \left(\varphi_2^{MIN}/\varphi_1^{MIN}\right)^k$ measures the technological asymmetry across countries. Regarding this measure of asymmetry we need to impose a parameter restriction, which states that the asymmetry has to be modest relative to trade openness, namely $\chi > \phi$. There exists the following link between the domestic cutoff and the export cutoff which deter-

[11] Note that $\widetilde{\varphi}_i \neq \widetilde{\varphi}_{ti}$, where φ_{ti} is the average productivity among all (domestic and foreign) active firms in market i.

mines the threshold productivity needed to serve the export market: $\varphi_{xj}^* = \Lambda\varphi_i^*$, where $\Lambda \equiv \left[\tau \left(f_x/f\right)^{1/(\sigma-1)}\right]$ and $\Lambda > 1$ due to $f_x \geq f$. We can then obtain the following ranking of productivity cutoffs, assuming that country 1 is the leading country and country 2 is the laggard country in terms of technology ($\chi < 1$): $\varphi_{x2}^* > \varphi_{x1}^* > \varphi_1^* > \varphi_2^*$. The domestic cutoff in country 1 is higher than in country 2 and hence, due to $\varphi_{xj}^* = \Lambda\varphi_i^*$, the export cutoff in country 1 is lower than in country 2. The high productive firms from the leading country 1 find it easier to export to country 2, facing less productive firms and softer competition. The opposite holds for the laggard country 2. Firms are less productive and exporters face tougher competition in country 1.

The allocation of the workforce which is employed in the manufacturing sector completes the description of the open economy equilibrium. To derive it, we use the aggregate trade balance condition for country 1:

$$M_1 p_{x1} r_{x1}\left(\widetilde{\varphi}_{x1}\right) = M_2 p_{x2} r_{x2}\left(\widetilde{\varphi}_{x2}\right) + \left(1 - t_1 - \beta\right) - \left(1 - \gamma_1\right). \tag{15}$$

The LHS of the trade balance condition denotes the value of country 1's manufacturing exports. The RHS of the equation consists of the manufacturing imports from country 2 and, if manufacturing trade is not balanced between both countries, the net exports of the numeraire (represented by the sum of the second and third term of the RHS). Appendix A proves that the labor share allocated to the manufacturing sector in country $i = 1, 2$ is given by:

$$\gamma_1 = \beta\left(\frac{1 - 2\phi\chi}{1 - \phi\chi} + \frac{\phi}{\chi - \phi}\right) + t_1 \quad \text{and} \quad \gamma_2 = \beta\left(\frac{1}{1 - \phi\chi} - \frac{\phi}{\chi - \phi}\right) + t_2. \tag{16}$$

The equations clearly show that a higher tax rate t_i increases the share of labor allocated to the manufacturing sector. This is because the lump-sum tax reduces the consumption of the numeraire and increases the minimum productivity. Analyzing (16) shows that $\gamma_1 = \gamma_2 = \beta + t$ if countries are symmetrical regarding their technology level ($\chi = 1$) and that $\gamma_i = \beta + t_i$ if trade costs are prohibitive ($\phi \to 0$). Because we want to ensure that the numeraire sector is still active after trade, we need to impose parameter restrictions such that $0 < \gamma_i < 0$ for $i = 1, 2$, which are written down in appendix A in detail. These restrictions require technology asymmetries to be modest relative to trade openness and per-capita manufacturing expenditure β and taxes t_i to be sufficiently small. Using γ_1 and γ_2, it is now straightforward to derive the equilibrium masses of entrants, M_i^E, surviving domestic firms, M_i, exporting domestic firms, M_{xi}, and consumed varieties, $M_{ti} =$

$M_i + M_{xj}$, for both countries. The price index in the open economy is given by $P_i = M_{ti}^{1/(1-\sigma)} / (\rho \widetilde{\varphi}_{ti})$, where $\widetilde{\varphi}_{ti}$ is the average productivity among all active firms in market i. Finally, indirect utility in country i can be written as:

$$V_i = y + \beta \ln \varphi_i^* + \frac{\beta}{\sigma - 1} \ln L + \kappa_1, \tag{17}$$

which is proportional to the domestic cutoff productivity φ_1^*.

4 Technology Investments without Spillovers

We now turn to the determination of the endogenous technology investments. We assume that both countries have the same and normalized technology level if there are no investments in any country. We first deal with the Nash-equilibrium, which results if both countries behave non-cooperatively, before addressing the case where they cooperatively set their policies. Tax income and investment level in country i are denoted by T_i. Analogous to the closed economy the government in country i invests T_i and the technology level is given by $H(T_i)$. The minimum productivity draw in country i is given by:

$$\varphi_i^{MIN} = \exp\{H(T_i)\}. \tag{18}$$

At this point we assume that technology investments in country i do *not* affect the minimum productivity draw in the other country. Hence, there are no spillovers of technology investments across countries.

4.1 Nash-Equilibrium Policy

Welfare in country i is given by:

$$V_i = 1 - T_i + \beta \ln \varphi_i^* + \frac{\beta}{\sigma - 1} \ln L + \kappa_1 = 1 - T_i + \beta \ln \left(\varphi_i^{MIN} \left(\frac{\bar{\chi}}{\bar{\chi} - \phi} \right)^{1/k} \right) + \kappa_3, \tag{19}$$

where $\bar{\chi} = \varphi_j^{MIN}/\varphi_i^{MIN}$ is the relative technology and $\kappa_3 = \kappa_2 + \frac{\beta}{k}\ln(1-\phi^2)$ is a constant.[12] The necessary condition for a welfare optimum is the FOC given by:

$$\frac{\partial V_i}{\partial T_i} = -1 + \beta H'(T_i) + \frac{\phi\beta H'(T_i)}{\left(\exp\left\{H(T_j) - H(T_i)\right\}\right)^k - \phi} = 0. \tag{20}$$

It can be shown that there exists a symmetric Nash-equilibrium policy such that both countries set the same tax rate $T = T_i = T_j$ and the FOC simplifies to:

$$\text{FOC} = -1 + \beta H' + \underbrace{\frac{\phi}{(1-\phi)}\beta H'}_{\text{trade effect}} = 0. \tag{21}$$

In appendix A we show that this Nash-equilibrium satisfies the second-order condition for a welfare maximum. Using equation (21) we can clearly disentangle the different effects of higher investments in technology. Investments T increase the lump-sum tax, which has a negative marginal unit welfare burden. However, they also increase the minimum productivity, rising the cutoff and average productivity, decreasing the price index, and at the end increasing welfare. By considering the FOC, the positive effect of investments in technology can be split into two parts. The already known effect $\beta H'$ we discussed in the autarky case and the new "trade effect" $\phi\beta H'/(1-\phi)$. To develop economic intuition for the trade effect, consider a scenario in which country 1 invests in technology, while country 2 does not. Hence country 1 is the leading and country 2 is the laggard country in terms of technology. The direct positive effect of investments in technology by country 1 is that they increase the domestic cutoff φ_1^*. Furthermore, they also decrease the foreign cutoff φ_2^*. Hence, investments in technology generate a negative cross-country externality to foreign firms. Concerning the export markets it is now harder for country 2 firms to serve country 1, and it is easier for country 1 firms to serve the foreign market country 2: $\varphi_{x2}^* > \varphi_{x1}^*$. The comparative advantage of country 1 firms in serving the foreign market is even more important, the higher the profit from international trade is, i.e. the higher the trade freeness ϕ is. This effect mirrors the strategic incentive for governments to invest in technology. The higher trade freeness is, the higher is the governments' incentive to give domestic firms a competitive advantage in competition with foreign firms. Hence, trade liberalization should increase investments in technology. To see this analytically, define

[12] Again we have to impose that asymmetry has to be modest relative to trade openness, namely $\bar{\chi} > \phi$.

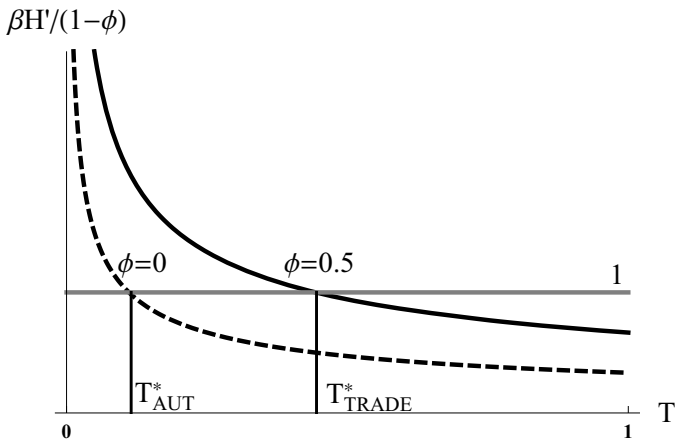

Figure 3: Optimal investment level T^* under autarky and in the open economy without spillovers

$\zeta = \beta H'/(1-\phi) - 1$, and use the implicit function theorem to derive:

$$\frac{\partial T}{\partial \phi} = -\frac{\partial \zeta}{\partial \phi}\left(\frac{\partial \zeta}{\partial T}\right)^{-1} = -\frac{H'}{(1-\phi)H''} > 0. \tag{22}$$

Result 2: Nash-equilibrium policy without spillovers: Trade liberalization leads to higher investments in technology.[13]

Figure 3 illustrates the autarky equilibrium and the open economy equilibrium without spillovers. In both cases the unit welfare burden is constant (gray line) while the decreasing functions denote the welfare increase due to a higher minimum productivity. As the comparison between the dashed line (autarky) with the black solid line (open economy with $\phi = 0.5$) shows, the optimal investment level under autarky is lower than in the open economy.

[13]To illustrate result 2 consider the following example: Let $H = \sqrt{T}$. Then we have $H' = 1/\left(2\sqrt{T}\right)$. Solving $H' = (1-\phi)/\beta$ for the optimal tax rate leads to $T^* = \beta^2/\left(4(1-\phi)^2\right)$.

4.2 Cooperative Policy

Now consider the scenario, where countries cooperatively set their policies. Joint welfare Ω of both countries is given by:

$$\Omega = V_1 + V_2 = 1 - T_1 + \beta \ln \varphi_1^* + \frac{\beta}{\sigma - 1} \ln L_1 + 1 - T_2 + \beta \ln \varphi_2^* + \frac{\beta}{\sigma - 1} \ln L_2 + \kappa_4, \quad (23)$$

where $\kappa_4 = 2\kappa_1$ is a constant. The necessary condition for a welfare optimum for country 1 is given by:

$$\frac{\partial \Omega}{\partial T_1} = -1 + \beta \left(2 + \frac{\phi}{\exp\{\cdot\} - \phi} + \frac{1}{-1 + \exp\{\cdot\}\phi} \right) H'(T_1) = 0, \quad (24)$$

where the argument of the exponential function is suppressed to simplify notation and given by $\exp\{\cdot\} = \exp\{k(-H(T_1) + H(T_2))\}$. For country 2 the FOC is the following:

$$\frac{\partial \Omega}{\partial T_2} = -1 + \beta \left(-\frac{\phi}{(\exp\{\cdot\})^k - \phi} + \frac{1}{1 - (\exp\{\cdot\})^k \phi} \right) H'(T_2) = 0, \quad (25)$$

where the argument of the exponential function is again suppressed and given by $\exp\{\cdot\} = \exp\{-H(T_1) + H(T_2)\}$. Imposing $T_1 = T_2 = T$ due to symmetry yields the simplified FOC as follows:

$$\text{FOC} = -1 + \beta H' = 0. \quad (26)$$

Result 3: Cooperative policy without spillovers: The cooperative solution is equivalent to the autarky policy. Trade liberalization leads to no change in the investments in technology compared to the autarky case.

In the Nash-equilibrium policy trade liberalization leads to higher investments compared to the autarky scenario, and thus to over-investments in technology from a social perspective. The economic intuition is straightforward. Technology investments lead to a negative cross-country externality that is not taken into account in the Nash-equilibrium policy. This negative externality is internalized in the cooperative solution, and thus leads to lower investments than in the Nash-equilibrium policy.

5 Technology Investments with Spillovers

We now relax the somehow restrictive assumption that technology investments solely affect the minimum productivity of the home country. Henceforth we assume that home investments in technology also generate a spillover to the minimum productivity draw in the foreign country.[14] Doing so, we introduce another channel how trade liberalization impacts the equilibrium outcome. The government in country i invests T_i and the technology level in country i, induced by home investments, is $H(T_i)$. However, the overall technology level in country i is also positively affected by investments T_j of the foreign country j. The foreign part of technology improvement is denoted by $F(T_j)$. Even if countries are identical with respect to country size and the return of investments, our notation allows for a separation of the technology improving impact of domestic and foreign investments in technology. For both H and F we assume that investments in technology generate positive but decreasing marginal returns, formally:

$$H' = \frac{\partial H}{\partial T_i} > 0 \quad \text{and} \quad H'' = \frac{\partial H'}{\partial T_i} < 0, \quad F' = \frac{\partial F}{\partial T_j} > 0 \quad \text{and} \quad F'' = \frac{\partial F'}{\partial T_j} < 0.$$

The minimum productivity draw in the home country i is given by:

$$\varphi_i^{MIN} = \exp\{H(T_i) + \phi F(T_j)\} \tag{27}$$

and it is clear that the minimum productivity draw now positively depends on not only the home investment level T_i but also on the investments T_j of the foreign country j. The impact of the spillover ϕF increases in ϕ, since we consider trade openness ϕ as a broad measure of economic integration. The spillover is then more pronounced, the more the economies are integrated.[15] We typically expect that investments in technology have a stronger impact on the domestic minimum productivity level than on the foreign minimum productivity. We define $\Delta \equiv H' - F'$ and call the typical case of $\Delta > 0$ a "weak spillover". Nevertheless, in certain cases, investments in education may have a stronger impact to a foreign country than to the home country. This may be the case, for instance, in some

[14] See also the industrial organization literature on R&D spillovers, e.g. Cohen and Levinthal (1989). They argue that R&D investments not only lead to a new product innovation but may also impact the other firm's ability to assimilate and exploit their production technologies.

[15] See Adams (1990), Jaffe (1989) and Branstetter (2001) for empirical evidence that e.g. patent citations actually decrease in distance. Or as the authors (Jaffe et al., 1998, p.968) note "spillovers are limited to specific areas and not just the diffuse effect of a large research university." Hence for our model these studies also suggest that the magnitude of the spillover positively depends on the trade openness.

small countries like Hong Kong, whose educational quality is very high and attracts many students from foreign countries. Thus Hong Kong's investments in education may have a stronger impact to foreign countries than to Hong Kong itself. For situations like that, we assume $\Delta < 0$ and call it a "strong spillover".

5.1 Nash-Equilibrium Policy

Welfare in country i is given by:

$$V_i = 1 - T_i + \beta \ln \varphi_i^* + \frac{\beta}{\sigma - 1} \ln L + \kappa_1 = 1 - T_i + \beta \ln \left(\varphi_i^{MIN} \left(\frac{\bar{\chi}}{\bar{\chi} - \phi} \right)^{1/k} \right) + \kappa_3, \quad (28)$$

where $\bar{\chi} = \varphi_j^{MIN} / \varphi_i^{MIN}$ is the relative technology and $\kappa_3 = \kappa_2 + \frac{\beta}{k} \ln (1 - \phi^2)$ is a constant. The necessary condition for a welfare optimum is the FOC given by:

$$\frac{\partial V_i}{\partial T_i} = -1 + \beta H' (T_i) + \frac{\phi \beta H' / T_i) - \phi^2 \beta F' (T_1)}{\left(\exp \left\{ H (T_j) - H (T_i) + \phi F (T_i) - \phi F (T_j) \right\} \right)^k - \phi} = 0. \quad (29)$$

It can be shown that there exists a symmetric Nash-equilibrium policy such that both countries set the same tax rate $T = T_i = T_j$ and the FOC simplifies to:

$$\text{FOC} = -1 + \overbrace{\underbrace{\frac{1}{(1 - \phi)} \beta H'}_{\text{trade effect}} - \underbrace{\frac{\phi^2}{(1 - \phi)} \beta F'}_{\text{spillover effect}}}^{\text{marginal benefit}} = 0. \quad (30)$$

In appendix A we show that this Nash-equilibrium satisfies the second-order condition for a welfare maximum. Formally the marginal benefit of investments in technology can be split into two parts. The already known trade effect (see section 4.1) and the new "spillover effect". Both increase in trade openness ϕ but have opposite signs. If the trade (spillover) effect dominates, trade integration leads to higher (lower) investments in technology.
Comparing the FOCs with and without spillovers of investments in technology, for a given level of trade openness ϕ, we can clearly see that without spillovers (Eq.(21)) the investment level T is always higher as it is the case with spillovers (Eq.(30)). With spillovers, investments in technology have the characteristic of a public good, i.e. not only the domestic firms benefit from the investments but also the foreign firms. Hence, the spillover effect dampens the marginal benefit of the investment policy because home firms now gain

less competitiveness relative to foreign firms.[16] With higher trade openness this "free rider" problem, that arises due to the public goods character of investments, becomes even more important and dampens the government incentive to invest.
With the help of the implicit function theorem and $\zeta = \frac{\beta}{1-\phi}H' - 1 - \frac{\beta\phi^2}{1-\phi}F'$ we derive:[17]

$$\frac{\partial T}{\partial \phi} = \frac{\partial \zeta}{\partial \phi}\left(\frac{\partial \zeta}{\partial T}\right)^{-1} = \frac{H' + (-2+\phi)\,\phi F'}{(1-\phi)\,(\phi^2 F'' - H'')}. \tag{31}$$

If we assume a weak spillover, i.e. $\Delta = H' - F' > 0$, we get:

$$\frac{\partial T}{\partial \phi} = \frac{\partial \zeta}{\partial \phi}\left(\frac{\partial \zeta}{\partial T}\right)^{-1} = -\frac{H'\,(1-\phi^2) + \Delta\,(2-\phi)\,\phi}{(1-\phi)\,(1-\phi^2)\,H''} > 0. \tag{32}$$

Result 4: Nash-equilibrium policy with weak spillovers: Trade liberalization increases investments in technology.

Hence, for weak spillovers and without spillovers (see Result 2) trade liberalization leads to higher investments in technology in Nash-equilibrium policy. A natural question is whether this result also holds for strong spillovers. Put differently, we ask ourselves if there is a case in which trade liberalization actually leads to lower investments in technology? Solving $\frac{\partial T}{\partial \phi} = 0$ for ϕ leads to:

$$\bar{\phi} = 1 - \frac{\sqrt{F'\,(F' - H')}}{F'} = 1 - \sqrt{\frac{-\Delta}{F'}}, \tag{33}$$

with $\bar{\phi} < 1$ if and only if $\Delta < 0$, which mirrors a strong spillover of technology investments to the foreign country. Hence, for a sufficiently high trade openness $\phi > \bar{\phi}$, investments in technology decrease with further trade liberalization. Note that a lower Δ mirrors a stronger spillover to the foreign country, and the incentive to decrease investments starts at a lower trade openness ϕ since $\bar{\phi}$ decreases with lower Δ.

Result 5: Nash-equilibrium policy with strong spillovers: Trade liberalization first leads to an increase and then to a decrease of investments (hump-shaped relationship).[18]

[16] The result that the level of investments is lower in cases where spillovers exist is a well known result in the industrial organization literature on investments in R&D, see e.g. Spence (1984) as a seminal reference.

[17] Note that if the impact of the foreign technology investment level is zero, i.e. $F' = 0$ and $F'' = 0$, Eq.(31) reduces to $\frac{\partial T}{\partial \phi} = -\frac{H'}{(1+\phi)H''} > 0$ what is equivalent to Eq.(22) derived in the case without spillovers.

[18] To illustrate results 4 and 5 consider the following example: Let $H = \sqrt{T}$ and $F = s\sqrt{T}$, where s is the strength of the spillover. Thereby $0 < s < 1$ denotes a weak spillover and $s > 1$ denotes a strong

Why do countries decrease investments in technology with higher trade openness? The reason is that with strong spillovers the total effect (marginal benefit) of trade integration can actually be negative. In this case the spillover effect outweighs the trade effect. In this context, recall the example of Hong Kong, where investments in education might convey foreign countries more than the domestic country itself.

5.2 Cooperative Policy

Now consider the cooperative solution. The joint welfare function of both countries Ω is given by:

$$\Omega = V_1 + V_2 = 1 - T_1 + \beta \ln \varphi_1^* + \frac{\beta}{\sigma - 1} \ln L_1 + 1 - T_2 + \beta \ln \varphi_2^* + \frac{\beta}{\sigma - 1} \ln L_2 + \kappa_4, \quad (34)$$

where $\kappa_4 = 2\kappa_1$ is a constant. The necessary condition for a welfare optimum is the FOC. For country 1 it is given by:

$$\frac{\partial \Omega}{\partial T_1} = -1 + 2\beta H'(T_1) + \beta \left(\frac{\phi H'(T_1) - \phi^2 F'(T_1)}{\exp\{\cdot\}^k - \phi} - \frac{H'(T_1) - \phi F'(T_1)}{1 - \exp\{\cdot\}^k \phi} \right) = 0, \quad (35)$$

where the argument of the exponential function is suppressed to simplify notation and given by $\exp\{\cdot\} = \exp\{\phi F(T_1) - \phi F(T_2) - H(T_1) + H(T_2)\}$. For country 2 the FOC is given by:

$$\frac{\partial \Omega}{\partial T_2} = -1 + 2\beta\phi F(T_2) + \beta \left(\frac{\phi^2 F'(T_2) - \phi H'(T_2)}{\exp\{\cdot\}^k - \phi} + \frac{\phi F'(T_2) - H'(T_2)}{-1 + \exp\{\cdot\}^k \phi} \right) = 0, \quad (36)$$

where the argument of the exponential function is again suppressed and given by $\exp\{\cdot\} = \exp\{\phi F(T_1) - \phi F(T_2) - H(T_1) + H(T_2)\}$. Imposing $T_1 = T_2 = T$ yields the simplified FOC as follows:

$$\text{FOC} = -1 + \beta H' + \beta\phi F' = 0. \quad (37)$$

spillover. Solving the FOC for the optimal tax rate yields $T^* = \frac{\beta^2 \left(1 - s\phi^2\right)^2}{4(1-\phi)^2}$. T^* reaches its maximum at $s = 1/\phi^2 > 1$. Hence, there exists only a maximum for $0 < T^* < 1$ if $s > 1$, which mirrors a strong spillover.

We use the implicit function theorem and $\zeta = -1 + \beta H' + \beta\phi F'$ to derive:

$$\frac{\partial T}{\partial \phi} = -\frac{\partial \zeta}{\partial \phi}\left(\frac{\partial \zeta}{\partial T}\right)^{-1} = -\frac{F'}{\phi F'' + H''} > 0. \tag{38}$$

Result 6: Cooperative policy with spillovers: Trade liberalization leads to higher investments in technology.

In comparison to the cooperative policy without spillovers (Eq.(26)) we find a positive impact of trade openness on the investment level. The economic reason is that investments in the scenario with spillovers do not only improve the domestic firms' technology level but they also generate a positive externality on the technology of foreign firms. The latter effect is stronger, the higher the degree of trade openness. In comparison to the Nash-equilibrium policy the spillover does not dampen the incentive to invest. Exactly the opposite it true. Spillovers lead to a positive externality to the foreign country that is internalized in the cooperative solution and increases in ϕ.
To compare the cooperative policy with the Nash-equilibrium policy we rewrite the FOCs Eq.(30) and Eq.(37), respectively. They are given by:

$$\text{FOC}_{\text{Coop}} = -1 + \beta H' + \beta\phi F' = 0 \tag{39}$$

and

$$\text{FOC}_{\text{Nash}} = -1 + \beta H' + \beta\phi F' + \frac{\phi}{1-\phi}\beta\Delta = 0. \tag{40}$$

Both FOCs only differ in the last term of Eq.(40). The sign of Δ depends on whether the investments spillover is weak or strong. If the spillover to the foreign country is strong ($\Delta < 0$), the investment level T^*_{Nash} in the Nash-equilibrium policy is then lower than the welfare maximizing investment level T^*_{Coop} of the cooperative solution. If the spillover is weak ($\Delta > 0$) the investment level T^*_{Nash} in the Nash-equilibrium policy is then higher compared to the cooperative solution T^*_{Coop}.

Result 7:

(i) Weak Spillover: Nash-equilibrium policy invests too much from a social perspective and we have an over-investment problem: $T^*_{\text{Coop}} < T^*_{\text{Nash}}$.

(ii) Strong Spillover: Nash-equilibrium policy invests too little from a social perspective and we have an under-investment problem: $T^*_{\text{Nash}} < T^*_{\text{Coop}}$.

In the open economy there are two motives for governments to invest in technology. Firstly, there is the benevolent motive. Investments in technology improve welfare due to a lower CES price index. Secondly, there is the strategic motive of investments in technology. Governments have an strategic incentive to give their domestic firms a competitive advantage over foreign firms. In the cooperative solution, only the benevolent motive is taken into account, and all strategic motives of cross-country externalities are internalized. The magnitude of the strategic motive crucially depends on the strength of the spillover. Without or with weak spillovers the government strategically over-invests and with strong spillovers the government under-invests in technology.

6 Conclusion

6.1 Summary

In this paper we have developed a two-country model where governments can invest in technology to improve firms' average productivity. We find that in the closed economy countries have an incentive to invest if consumers have a sufficiently high preference for varieties. In the open economy there are two motives for this policy. First, the benevolent motive is to decrease the average price, which leads to a consumption gain. Second, the strategic motive is to generate a negative cross-country externality to the foreign country, which gives domestic firms a competitive advantage over foreign firms. This strategic motive to invest in technology might also be supported by the fact that investments in technology are not considered as a common trade policy. Therefore this instrument is not under scrutiny by international organizations like the WTO as classical trade policy instruments like import tariffs or export subsidies. However, in our context with heterogeneous firms we definitely find that trade patterns are affected by the strategic use of investments in technology.

If there are no cross-country investment spillovers, the cooperative solution is equivalent to the autarky solution. If there are cross-country spillovers, countries invest more with higher trade openness. In the Nash-equilibrium policy countries strategically compete in their investment levels. If there are no cross-country spillovers, countries increase their investments with higher trade openness in order to take advantage of the negative cross-country externality to foreign firms. If there are cross-country investment spillovers, we differentiate between weak and strong spillovers. If there are weak (strong) spillovers, we find a positive (hump-shaped) relationship between investments and trade openness in

the Nash-equilibrium policy. From a social perspective we then obtain an over (under)-investment problem if spillovers are weak (strong).

6.2 A Brief Look into the Data

Our model provides a rationale why countries have an incentive to strategically invest in technology. It predicts a positive (humped-shaped) relationship between the minimum productivity draw and trade openness for weak (strong) spillovers. Unfortunately, the minimum productivity draw is unobservable in the data.[19] Nevertheless, we provide a brief empirical analysis whether this theoretical result is qualitatively supported by the data. As a real basic proxy for the country-specific investments in technology, we use the teacher-per-pupils ratio for 74 countries as reported by the World Bank (2006).[20,21] We augment this data set with information on trade openness at the country level, sticking to a standard proxy that has been widely used in the literature. The most common openness indicator is trade intensity (TI), which is defined for country i as the sum of total exports and imports over GDP: $TI_i = (Exp_i + Imp_i)/GDP_i$.[22] Matching data on the TI-measure by Penn World Table (2009) with the information on the teacher-per-pupils data by the World Bank (2006), we end up with a sample of 74 countries. Figure 4 plots the teacher-per-pupils ratio for 74 countries against the TI-measure and suggests a positive correlation. In fact, the simple OLS regression $(Teacher/Pupils)_i = \alpha + \beta_1 \cdot TI_i + \beta_2 \cdot (TI_i)^2 + \beta_3 \cdot laborproductivity_i + \epsilon_i$ has significant coefficients $\beta_1 > 0$ and $\beta_2 < 0$, which actually suggests that a humped-shaped relationship seems to fit the data.[23] This result is driven, however, by the countries with the highest openness levels like Hong Kong or Malaysia. For those countries it is most likely that investments in technology not only improve the domestic technological capabilities but also the foreign technology level of surrounding countries. In these cases the spillovers are probably "strong" ($\Delta < 0$) and our model predicts that trade liberalization

[19] Some authors like Corcos et al. (2009) provide indirect estimations for the minimum productivity using a Melitz and Ottaviano (2008) framework. For the 15 EU countries they provide estimations for the so called exogenous competitiveness, a bundle of sunk entry costs, factor prices, and the minimum productivity.

[20] The correlation coefficient of the teacher-per-pupils ratio with exogenous competitiveness by Corcos et al. (2009) is, depending on the set of sectors included, up to 0.52.

[21] See the UNESCO (2006) report on Teachers and Educational Quality.

[22] Trade intensity is the most basic trade indicator and easily available for a variety of countries from the Penn World Tables. See Rodriguez and Rodrik (2001) for a discussion on openness indices.

[23] More specifically, this simple OLS estimation yields $\beta_1 = 0.462^{***}$ (std.error 0.123), $\beta_2 = -1.517^{**}$ (std.error 0.459), $\beta_3 = 1.430^{***}$ (std.error 0.208) with $R^2 = 0.44$. Labor productivity is (GDP/employment) as reported by the International Labor Office (ILO). See appendix B for detailed data sources.

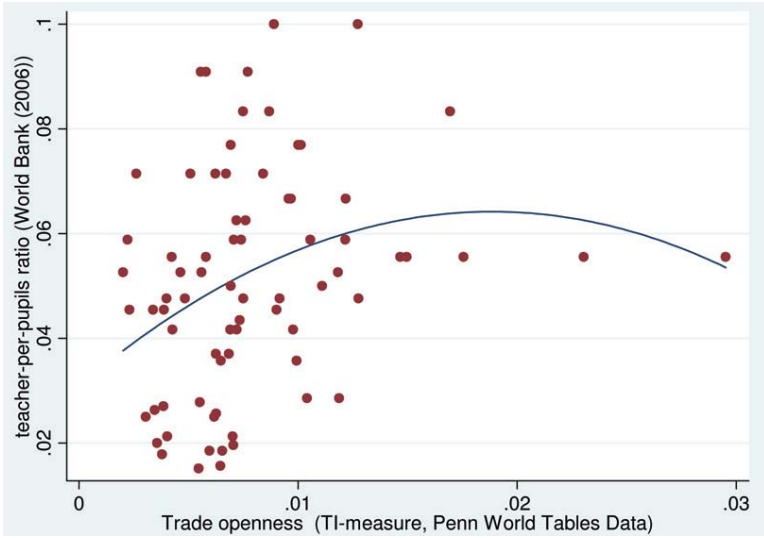

Figure 4: Trade intensity and teacher-per-pupils ratio

may actually lead to lower investments in technology.

For the vast majority of countries, figure 4 suggests that freer trade can go hand in hand with higher technology investments, which is qualitatively consistent with the predictions of our model. This conclusion is, of course, suggestive at best, especially since figure 4 makes no pretense of capturing any causal relationship between trade freeness and technology investments. A more detailed empirical analysis of these issues seems to be an interesting avenue for future research.

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Appendix A: Model

Equilibrium Firm Masses in the Open Economy

Using the fact that aggregate earnings in the manufacturing sector equal government spending and the revenue of manufacturing firms $\gamma_i = M_i \bar{r}_i + t_i$, with $\bar{r}_i = r_i(\widetilde{\varphi}_i) + p_{xi} r_{xi}(\widetilde{\varphi}_{xi})$ yields $M_i(\gamma_i - t_i)/\bar{r}_i$ for $i = 1, 2$. Substituting these terms into the trade balance condition for country 1 (Eq.(15)) and the analogous equation for country 2 gives the following expressions:

$$\frac{\gamma_1 - t_1}{1 + b_1} = \frac{\gamma_2 - t_2}{1 + b_2} + \gamma_1 - \beta - t_1 \qquad \frac{\gamma_2 - t_2}{1 + b_2} = \frac{\gamma_1 - t_1}{1 + b_1} + \gamma_2 - \beta - t_2, \tag{A1}$$

where

$$b_1 = \frac{r_1(\widetilde{\varphi}_1)}{p_{x1} r_{x1}(\widetilde{\varphi}_{x1})} = \frac{\tau^{\sigma-1}}{p_{x1}} \left(\frac{\widetilde{\varphi}_1 \varphi_2^*}{\varphi_1^* \widetilde{\varphi}_{x1}} \right)^{\sigma-1} = \frac{1}{\phi} \left(\frac{\varphi_2^*}{\varphi_1^*} \right)^k = \frac{1}{\phi} \left(\frac{\chi - \phi}{1 - \phi\chi} \right)$$

$$b_2 = \frac{r_2(\widetilde{\varphi}_2)}{p_{x2} r_{x2}(\widetilde{\varphi}_{x2})} = \frac{\tau^{\sigma-1}}{p_{x2}} \left(\frac{\widetilde{\varphi}_2 \varphi_1^*}{\varphi_2^* \widetilde{\varphi}_{x2}} \right)^{\sigma-1} = \frac{1}{\phi} \left(\frac{\varphi_1^*}{\varphi_2^*} \right)^k = \frac{1}{\phi} \left(\frac{1 - \phi\chi}{\chi - \phi} \right).$$

Solving (A1) for γ_i yields:

$$\gamma_1 = \beta \frac{(1 + b_1)(1 - b_2)}{1 - b_1 b_2} + t_1 \qquad \gamma_2 = \beta \frac{(1 - b_2)(1 - b_1)}{1 - b_1 b_2} + t_2. \tag{A2}$$

Plugging in b_1 and b_2 then leads to the expressions for γ_1 and γ_2 given in equation (16) in the text.

Furthermore, we need some parameter restrictions in order to ensure that $0 < \beta_i \equiv \gamma_i - t_i \leq 1$ for $i = 1, 2$. Country 2 is assumed to be the lagging country in terms of technology and we have $0 < \iota < 1$ for $\iota = \{\phi, \chi\}$. Now we impose the following conditions:

$$0 < \beta < \beta_{max} \equiv \frac{(\phi - \chi)(\phi\chi - 1)}{\chi(1 + \chi^2 - 2\phi\chi)} \quad \text{and} \quad 0 < \phi < \phi_{max} \equiv \frac{1 - \sqrt{1/\chi^2 - 1}}{\chi}. \tag{A3}$$

Conditions A3 require that per-capita manufacturing expenditure β and country asymmetries with respect to technology investments are sufficiently small. Using $M_i = (\gamma_i - t_i)/\bar{r}_i$ and γ_1, γ_2 yields the mass of domestic firms, mass of entrants, and mass of exporting firms:

$$M_1 = \frac{(\gamma_1 - t_1)}{\sigma(\bar{\pi}_1 + f + p_{x1} f_x)} = \frac{(k + 1 - \sigma)\beta}{\sigma k f} \frac{1 + \phi^2 - 2\phi\chi}{(1 - \phi^2)(1 - \phi\chi)} \tag{A4}$$

$$M_2 = \frac{(\gamma_2 - t_2)}{\sigma(\bar{\pi}_2 + f + p_{x2} f_x)} = \frac{(k+1-\sigma)\beta}{\sigma k f} \frac{(\chi(1+\phi^2) - 2\phi))}{(1-\phi^2)(\chi - \phi)}$$

$$M_1^E = \frac{\delta M_1}{(\varphi_1^{MIN}/\varphi_1^*)^k} = \frac{(\sigma-1)\beta}{\sigma k f_e} \frac{\chi(1+\phi^2-2\phi\chi)}{(\chi-\phi)(1-\phi\chi)} \tag{A5}$$

$$M_2^E = \frac{\delta M_2}{(\varphi_2^{MIN}/\varphi_2^*)^k} = \frac{(\sigma-1)\beta}{\sigma k f_e} \frac{(\chi(1+\phi^2) - 2\phi)}{(\chi-\phi)(1-\phi\chi)}$$

$$M_{x1} = \left(\frac{\varphi_1^*}{\Lambda\varphi_2^*}\right)^k M_1 = \frac{(k+1-\sigma)\beta}{\sigma k f_x} \frac{\phi(1+\phi^2-2\phi\chi)}{(1-\phi^2)(\chi-\phi)} \tag{A6}$$

$$M_{x2} = \left(\frac{\varphi_2^*}{\Lambda\varphi_1^*}\right)^k M_2 = \frac{(k+1-\sigma)\beta}{\sigma k f_x} \frac{\phi(\chi(1+\phi^2) - 2\phi)}{(1-\phi^2)(1-\phi\chi)}.$$

Finally from these expressions the mass of firms active in country i, $M_{ti} = M_i + M_{xj}$, (i.e. consumption variety) can be obtained.

Nash-Equilibrium Policy

In the following we show that the Nash-equilibrium satisfies the second-order conditions for a welfare maximum. Firstly, consider the case without spillovers. Differentiating Eq.(20) with respect to T_i and using the FOC $H'(T) = (1-\phi)/\beta$, leads to:

$$\text{SOC} = \frac{k\phi}{\beta} + \left(\frac{\beta}{1-\phi}\right) H'' < 0, \tag{A7}$$

which is satisfied for a sufficiently low ϕ. Secondly, consider the case with spillovers. Differentiating Eq.(29) with respect to T_i and using the FOC $H'(T) = (1-\phi+\beta\phi^2 F')/\beta$, leads to:

$$\text{SOC} = \frac{\phi\left(k(1-\phi)(1-\beta\phi F')^2 - \beta^2\phi F''\right)}{\beta(1-\phi)} + \frac{\beta}{(1-\phi)} H'' < 0, \tag{A8}$$

which is also satisfied for a sufficiently low ϕ.

Appendix B: Data

List of Countries included in the Empirical Analysis (N=74):

Argentina, Armenia, Austria, Belgium, Bolivia, Brazil, Bulgaria, Burkina Faso, Chile, China, Colombia, Croatia, Denmark, Dominican Republic, Ecuador, Egypt, Finland, France, Georgia, Germany, Ghana, Greece, Hong Kong, Hungary, India, Indonesia, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Korea Rep., Kyrgyz Republic, Latvia,

Lebanon, Lithuania, Madagascar, Malawi, Malaysia, Mexico, Morocco, Mozambique, New Zealand, Nigeria, Norway, Pakistan, Panama, Peru, Philippines, Poland, Portugal, Romania, Russian Federation, Senegal, Singapore, Slovak Rep., Slovenia, South Africa, Spain, Sri Lanka, Sweden, Tanzania, Thailand, Tunisia, Uganda, Ukraine, United Kingdom, United States, Uruguay, Venezuela, Zambia, Zimbabwe.

Data Sources:

Teacher-per-pupils	World Bank (2006), World Development Indicators 2006.
TI_i	TI-based trade openness measure for the year 2000, Penn World Tables.
Employment	Total employment level for 1999 (in 1,000,000), International Labour Office (ILO), LABORSTA - data base for labor statistics.

Note for the interpretation of the OLS regression that TI_i is multiplied by 1,000.