Corporate Income Taxation and Multinational Production*

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Abstract

Empirical evidence shows that corporate income taxation has a significant effect on multinational firms' location and production decisions. In this paper, I develop a quantitative general equilibrium model to examine the channels through which corporate taxes affect multinational production (MP) and international trade. The rich, yet highly tractable, model embeds corporate taxation as a novel friction to trade and MP, in addition to including the common international frictions in existing quantitative MP models. To shed light on the model's implications, I calibrate a three-country version of the model to data on trade, multinational production, and corporate tax rates for Germany, Ireland, and the United States. I compute the Nash equilibrium tax rates and find that Germany and the US would incur larger tax cuts than Ireland. Counterfactual analysis reveals that all three countries would gain from moving to the Nash tax rates but lose if corporate taxation is eliminated.

JEL Codes: F12, F23, F40, H21, H25, H32, L23

Keywords: Multinational firms, corporate taxes, international taxation, tax competition

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1 Introduction

Multinational enterprises (MNEs) are instrumental to the process of globalization. Not only do they account for two-thirds of world trade, but they also operate internationally and comprise roughly a quarter of world GDP (UNCTAD (1996, 2000)).[1] The growing importance of MNEs in the global economy has received great attention from researchers. A recent international trade literature on multinational production (MP) is dedicated to developing general equilibrium models, which can be used to examine various factors affecting MNEs' location and production decisions and to quantify welfare gains from openness.[2] In this paper, I consider an important determinant of MNEs' decision-making process that has never been systematically studied in previous quantitative trade and MP work, namely, corporate income taxation. The last two decades have witnessed worldwide corporate tax cuts. Countries that experienced the largest reduction in tax rates, such as Ireland, have become MNEs' favorite production locations. Previous quantitative trade and MP models, which imply the standard gravity equation, fail to capture the particular attractiveness of such countries to multinationals.[3] This paper provides the first general equilibrium framework suitable for examining such phenomenon and evaluating corporate tax policies designed to attract multinational firms.

Evidence supporting the impact of corporate income taxes on multinational production is well documented in the empirical international taxation literature. However, a quantitative general equilibrium framework is necessary in order to explore the channels through which

[1] Foreign affiliates alone are responsible for one-third of world trade and 10 percent of world GDP, according to the World Investment Report (UNCTAD (1999, 2007)).

[2] See Arkolakis et al. (2013), Garetto (2013), Irarrazabal et al. (2013), Ramondo and Rodríguez-Clare (2013), Tintelnot (2017), and more recently, Fan (2017), Sun (2017), and Wang (2016). Factors studied in existing quantitative research include comparative advantage of foreign affiliates in production, market-entry costs and shipping costs, and costs of establishing foreign affiliates. A more detailed review and discussion on these papers can be found toward the end of this section, under "Related Literature".

[3] The standard gravity equation of trade (or MP) states that bilateral trade (or MP) between two countries depends on relative size of the countries, measured by their GDP, and the standard trade (or MP) barriers between them, such as distance, contiguity, and common language.

taxes affect MP and trade and to quantify the welfare implications of tax policies. The model I develop in this paper is rich enough to capture the various determinants of firms' MP and export decisions but simple enough to yield a system of equations for the equilibrium outcomes that can be solved numerically. I calibrate a three-country version of the model to data on trade, MP, and corporate tax rates for Germany, Ireland, and the United States. I then compute the Nash equilibrium corporate tax rates and calculate the associated welfare changes. The United States would undertake the largest tax cut in the Nash equilibrium, in an attempt to widen market entry of marginal firms. All three countries would experience welfare gains under the Nash tax rates. I proceed with a series of counterfactual exercises to shed light on the welfare implications of corporate income taxation through its distortion on multinational production and international trade. I find that all three countries would be worse off if corporate taxation is eliminated due to the loss in tax revenue. However, the effect of zero tax rate on trade and MP varies across countries. Following the convention in the MP literature, I also calculate welfare gains from MP, trade, and openness. My result is consistent with the general findings, revealing that small countries benefit more from an open regime.

Existing empirical support for the role that corporate taxes play in MNEs' decision-making process typically relies on FDI data at the country level or financial statement data at the firm level. I demonstrate the importance of corporate income taxation with two new sets of multinational production data. First, I obtain data from the Bureau of Economic Analysis (BEA) and report the location choices of U.S. MNEs in 2013. A close look at the top 10 locations in terms of the number of affiliates, net income, and value added reveals that U.S. MNEs not only locate in countries with market potentials that can be explained by the standard gravity equation, but also favor countries with tax policies appealing to multinationals. Second, I explore a two-period cross-country dataset on tax rates and investment inflows. For a group of 23 countries, I find a negative relationship between the change in average inward MP shares (a measure of MP inflows) and the change in average statutory corporate income tax rates between 1996-2001 and 2006-2011. That is to say, countries with the largest tax cuts are the ones experiencing the largest increase in inward MP shares. This relationship is significant and robust.

Enlightened by these empirical findings, I explore the effect of corporate taxation on multinational production through the lens of a general equilibrium framework. I build upon two recent workhorse models on international trade and multinational production, i.e., Arkolakis et al. (2013) (henceforth ARRY) and Tintelnot (2017). Two main contributions of my model are (i) in addition to including the variable trade and MP costs commonly considered in the literature, it incorporates both fixed costs of establishing foreign plants (absent in ARRY in order to achieve tractability) and fixed marketing costs (absent in Tintelnot (2017) for simplicity), and (ii) it embeds corporate taxation as a novel friction, which affects firms' decisions and distorts international trade and multinational production. I use a two-stage maximization problem to characterize the firm's problem. I assume that, *ex ante*, firm heterogeneity is captured only by the vector of fixed MP costs drawn for all locations. In the first stage, given a vector of fixed MP costs, the firm chooses a set of potential production locations in order to maximize its expected net profits. In the second stage, the firm draws a location-specific productivity for each plant in the location set from a multivariate Pareto distribution. Then, for each destination market, it chooses a production location that maximizes its after-tax profits. If the profits are enough to cover the fixed marketing costs, then the firm will serve the market. Consistent with the empirical findings in the tax literature, the model delivers the predictions that corporate taxation affects MNEs' decisions at both the extensive margin (location choices) and the intensive margin (production choices). Specifically, the probability that a firm chooses a location set containing country x over a set that does not contain country x is a decreasing function of x's corporate tax rate; and, given a firm's location set choice (which contains x), the probability that the firm actually produces in x decreases with x's corporate tax rate. I aggregate up firms' decisions and obtain a system of equilibrium equations that can be solved numerically.

In order to minimize the computational burden arising from a large number of feasible production locations, the calibration focuses on three representative countries, namely Germany, Ireland, and the United States. Some parameters are calibrated externally, while the others are determined in the equilibrium. In particular, to calibrate the parameters governing fixed and variable trade and MP costs, I match the model-generated moments to data on trade shares, MP shares, the probability of becoming a domestic firm, and the number of foreign affiliates. With the calibrated model, I conduct a series of counterfactual exercises. First, I adapt an iterative algorithm to compute the Nash equilibrium tax rates. In the Nash equilibrium, all three countries would choose tax rates lower than the Baseline rates. Ireland would reduce its tax rate by 3 percentage points, whereas Germany and the United States would incur large reductions in tax rates, by 9 percentage points and 11 percentage points, respectively. The United States and Germany are endowed with larger numbers of firms, thus by undertaking large tax cuts, they are able to allow more potential firms to enter the market and thereby benefit more from the tax cut. In terms of changes in welfare, all three countries would experience welfare gains when moving to the Nash tax rates. Germany would benefit the most from the tax competition, seeing a 0.61% increase in welfare. Welfare in Ireland and the United States would increase by 0.28% and 0.46%, respectively. I then continue with a counterfactual exercise in which I eliminate corporate income taxes for all countries. I find that all countries would lose in this scenario, especially the ones for which tax revenue constitute a large portion of national income. Finally, I quantify gains from MP, trade, and openness. In line with the quantitative MP literature, I find that small countries like Ireland benefit more from openness than large countries.

Related Literature To my knowledge, this paper is the first to look at corporate income taxation in a general equilibrium international trade and multinational production framework. Nonetheless, it is closely related to several strands of literature.

As briefly mentioned above, the model I develop combines elements of ARRY and Tintelnot (2017). ARRY extend the Melitz (2003) model by allowing firms to produce outside their home country. Inspired by the Chaney (2008) version of Melitz (2003), they assume that plant-specific productivities are drawn from a multivariate Pareto distribution. By doing so, they obtain analytic expressions for the aggregate variables. I adapt the probabilistic representation of plant-specific productivity from ARRY, and assume that variable trade costs, variable MP costs, and fixed marketing costs are the frictions that impede global integration. However, I depart from ARRY by assuming that there also exist fixed MP costs (as in Tintelnot (2017)), which is a crucial element to explain the proximity-concentration tradeoff. ARRY abstract away this feature in order to achieve closed-form expressions for aggregate variables and a gravity equation for trade flows, but the downside is that their model cannot capture the fact that firms concentrate production in a few locations. I show that, with fixed MP costs added to my model, I still obtain a gravity equation for trade flows and a set of equilibrium equations that can be solved numerically. Certainly, adding fixed MP costs to the model makes it more complex to solve. Following Tintelnot (2017), who emphasizes the role of fixed MP costs in multinational production, I split the firms' problem into two stages, where the distribution of fixed MP costs determines the optimal set of locations for a firm in the first stage, and the second stage resembles ARRY except that the measure of firms originated in a country is exogenous. The merit of this modeling strategy is that, on the one hand, I could incorporate fixed MP costs to the model (as in Tintelnot (2017)), which is an essential factor but omitted in most studies due to tractability issues, on the other hand, assuming that productivities are drawn from a multivariate Pareto distribution (as in ARRY) gains tractability while avoiding the computationally intensive simulation methods used in Tintelnot (2017).

This paper is also related to a literature on international taxation, in particular, tax competition. I briefly discuss an influential model in this literature, Zodrow and Mieszkowski (1986) and Wilson (1986) (the ZMW model).[4] As will become clear, my model environment is very different from the tax competition models in urban and public economics. In the ZMW model, each local government provides a public good that is financed by a tax levied on the capital invested in its jurisdictions. The government's problem is to choose a tax rate on capital to maximize its representative consumer's utility, subject to a budget constraint requiring that tax revenue equals public good expenditures. The Nash equilibrium results in low tax rates and underprovision of the public goods. Models in this literature are usually partial equilibrium models. They simplify firms' strategies and ignore costs of interregional investment. Using an international trade framework, I model how taxes, together with other international frictions, affect firms' operating strategies. My model also departs from the traditional tax competition models by abstracting the role government plays. In particular, I do not model government as an agent in the economy who produces public goods with tax revenue. Instead, government simply collects taxes and rebates to consumers through a lump-sum transfer.

The rest of the paper proceeds as follows. Section 2 motivates the paper by describing empirical evidence on the relationship between corporate taxation and multinational production. Section 3 outlines the general equilibrium framework. Sections 4 and 5 calibrates the model and performs quantitative analysis. Section 6 concludes.

[4]See Keen and Konrad (2013), Wilson (1999), and Zodrow (2003) for comprehensive surveys of tax competition models in this literature.

2 Empirical Evidence

In this section, I provide empirical support for the relationship between corporate income taxation and multinational production. I first provide two new facts at the country level, which suggest that taxation could be an explanation to the location and investment patterns we see in the data. Then I turn to the firm-level evidence by discussing the findings in empirical tax studies. The importance of corporate taxes in MNEs' location and investment decisions motivates the model I develop in Section 3.

2.1 Location Choices of U.S. MNEs

Table 1: Top 10 Affiliate Locations of U.S. MNEs in 2013

	No. Affiliates	Net Income	Value Added
1	United Kingdom	**Netherlands**	United Kingdom
2	Canada	**Luxembourg**	Canada
3	**Netherlands**	**Ireland**	Germany
4	Germany	**Bermuda**	**Ireland**
5	China	Canada	France
6	France	**Switzerland**	China
7	Australia	United Kingdom	Australia
8	Mexico	**UK Is., Caribbean**	**Switzerland**
9	**Luxembourg**	**Singapore**	Japan
10	**Ireland**	Mexico	Brazil

Source: The annual survey of U.S. MNEs conducted by the Bureau of Economic Analysis (BEA).

Notes: Affiliates are majority-owned foreign affiliates in 2013. The highlighted countries are generally considered tax havens in the taxation literature.

Table 1 lists the top ten affiliate locations of U.S. MNEs in 2013, ranked by the number of affiliates, net income, and value added. U.S. multinationals' favorite locations roughly fall into three categories: (i) countries with geographical advantage (e.g. Canada, Australia, and Mexico), (ii) large countries, measured by GDP (e.g. United Kingdom, Germany, China, Japan, Brazil, and France), and (iii) the rest (highlighted), which I denote by tax havens. These countries are characterized by low tax rates, tax exemptions, and tax holidays that are particularly appealing to MNEs.[5]

Existing theoretical gravity models of international trade and multinational production can readily explain the role of geography and economic size in shaping trade and MP flows. However, none can fully rationalize the fact that tax havens are of particular interest to U.S. MNEs. In Figure 1, I plot MP flows from the U.S. to 132 host countries predicted by the standard gravity equation against their data counterparts. MP flows are measured by foreign affiliates' aggregate sales. I obtain the predicted values by regressing the log of affiliate sales on the standard gravity variables, i.e., GDP, distance, and common language. The 29 countries marked with red diamonds are tax havens reported by the U.S. Government Accountability Offices (U.S. GAO (2008)).[6] Most tax havens are below the 45 degree line, indicating that standard gravity models neglect tax havens' comparative advantage and systematically underpredict their MP flows.

As shown in column 2 of Table 1, in 2013, seven out of ten most profitable locations for U.S. MNEs are tax havens, which account for 60 percent of net income generated by all U.S. majority-owned foreign affiliates. It is worth noting that although MNEs locate in some tax havens, particularly small islands, for profit-shifting purposes, other tax havens do

[5]For definitions and characteristics of tax havens, see U.S. GAO (2008), OECD (2000), Hines Jr and Rice (1994), and Dharmapala and Hines (2009).

[6]These countries/territories are Anguilla, Antigua and Barbuda, Aruba, Bahamas, Bahrain, Barbados, Bermuda, Costa Rica, Cyprus, Gibraltar, Hong Kong, Ireland, Jordan, Latvia, Liberia, Luxembourg, Macau, Malta, Marshall Islands, Mauritius, Monaco, Panama, Samoa, Seychelles, Singapore, St. Kitts and Nevis, St. Lucia, Switzerland, and Vanuatu.

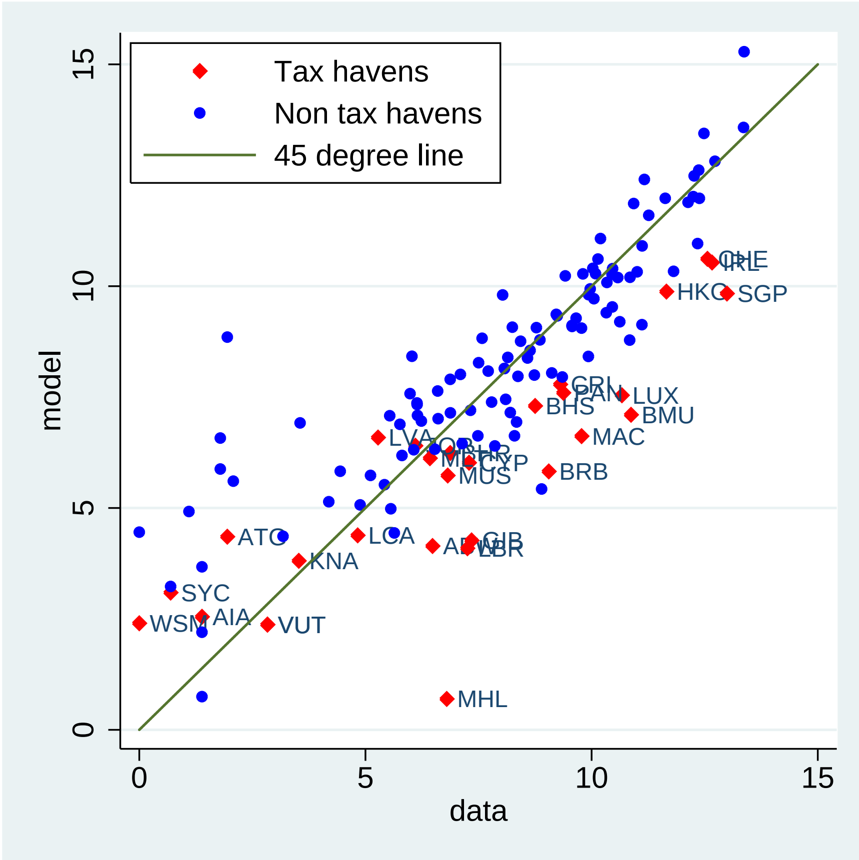

Figure 1: MP Flows: Gravity Model versus Data

Sources: MP flows are measured by foreign affiliates' sales in 2013, reported by the BEA. Standard gravity variables used in the estimation are from the CEPII Gravity Database.
Notes: This figure plots the gravity-model-predicted MP flows against the MP flows from the U.S. to foreign affiliates in the data .

contribute to production. In fact, Ireland and Switzerland are among the top ten locations in terms of value added (column 3 of Table 1). Since multinational production is the focus of this paper, I am silent about firms' profit-shifting strategies, and my framework is well suited to study the tax-driven production relocation of multinational firms.

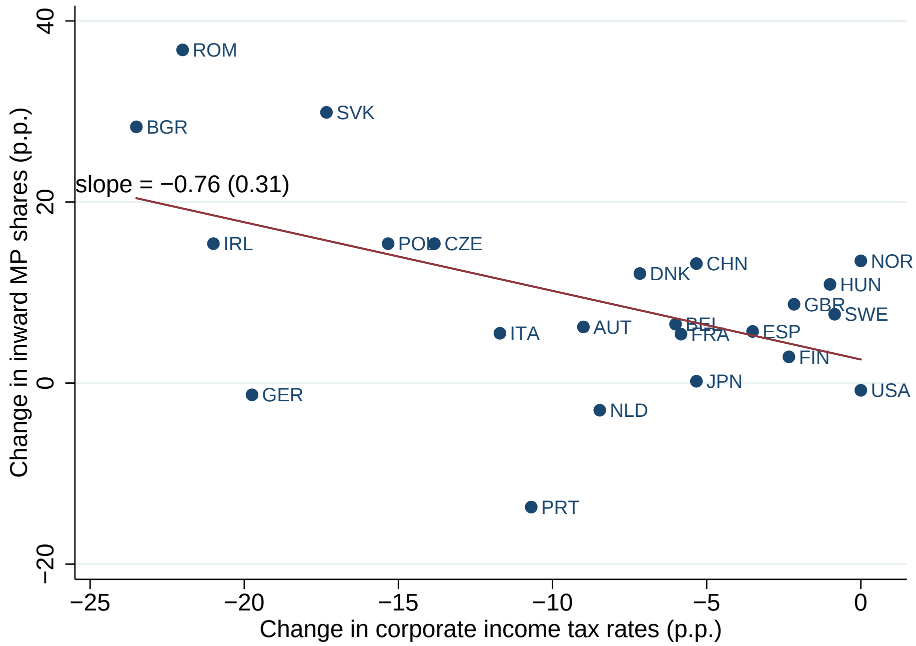

Figure 2: Changes in Statutory Corporate Tax Rates and Inward MP Shares (between 1996-2001 and 2006-2011)

Sources: Tax data come from Flaaen (2017), who compiles a time series data of statutory corporate tax rates from Office of Tax Policy at the University of Michigan, Ernst & Young, KPMG, and Loretz (2008). MP data are from Sun (2017), who uses bilateral MP data from Ramondo et al. (2015) for the period 1996-2001, and combines data from OECD and Eurostat to calculate inward MP shares for the period 2006-2011.

2.2 Tax Cuts and MP Changes

Governments are keen to use tax instruments to attract foreign investment. Over the last two decades, most countries have made major structural changes to their corporate income tax regimes, mainly by reducing tax rates and broadening tax bases. Between 2000 and 2011, the statutory corporate income tax rates in OECD member countries dropped on average by 7.2 percentage points, from 32.6% to 25.4%. To examine how MNEs' investment decisions adjust at the intensive margin, I plot the change in average inward MP shares against the change in average statutory corporate income tax rates between 1996-2001 and 2006-2011, for a group of 23 countries.[7] The inward MP share is defined as the share of foreign affiliates' output in total output produced in the country. Ramondo et al. (2015) provide a dataset that allows me to calculate the inward MP shares for 59 countries in 1996-2001. A recent paper by Sun (2017) combines data from the OECD and the Eurostat databases and computes this share for a group of 23 countries in 2006-2011. To calculate changes in tax rates, I use the statutory corporate tax rates dataset that Flaaen (2017) compiles with data from various sources. On average, corporate tax rates decreased by 9.2 percentage points and inward MP shares increased by 9.6 percentage points over this period. Figure 2 shows that countries with the largest tax cuts are the ones seeing the largest increase in inward MP shares. This is especially evident in small economies like Bulgaria, Czech Republic, Ireland, Poland, Romania, and Slovakia, which suggests that tax cuts might be more effective in attracting investments for small countries. The negative relationship between the change in inward MP shares and the change in corporate tax rates is significant and robust even after controlling for changes in GDP and tariffs.[8]

2.3 Evidence from the Empirical Tax Literature

A large empirical literature in public economics investigates the influence of corporate taxation on MNEs' decisions, both at the extensive margin (location choices) and at the intensive margin (investment decisions). On the extensive margin side, Devereux and Griffith (1998) build a partial equilibrium model that captures MNEs' decision-making process. They apply the model to a panel data of U.S. firms with affiliates in Europe and estimate the determinants of firms' location choices among three European countries using a nested multinomial logit model. They find that taxes are quantitatively significant in the choice of locations: a

[7] These countries are Austria, Belgium, Bulgaria, China, Czech Republic, Germany, Denmark, Spain, Finland, France, United Kingdom, Hungary, Ireland, Italy, Japan, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Sweden, and the United States.

[8] See Appendix B.1. for the complete regression results.

one percentage point increase in the effective average tax rate in the United Kingdom would lead to a 1.3 percentage points reduction in the probability of a U.S. firm choosing to produce there. The equivalent marginal effects for France and Germany and 0.5 percentage point and 1 percentage point, respectively.[9] An interesting yet rare study in this literature is a survey by Simmons (2000), who compiled a questionnaire and sent to the 500 largest MNEs in the world in 1996. These questions require the respondents to evaluate, on a scale of 1 to 10, the importance of a list of 22 potential determinants of affiliate locations. Around 100 responses were received, and the mean scores for the 22 determinants range from 4.12 to 7.73. Taxation of profits ranks in the eighth place, with a score of 6.66.[10] Empirical studies focusing on the intensive margin effect of taxes date back to Hartman (1984), who investigates the influence of domestic corporate tax policies in the United States to Foreign Direct Investment (FDI) inflows and finds the effect to be significant. Based on the tax return data of more than 500 U.S. MNEs in 1992, Grubert and Mutti (2000) show that tax rates in the 60 host countries have a significant effect on the amount of capital invested there. In particular, a lower tax rate associated with a one percent increase in the after-tax return to capital results in three percent more real capital invested if the country is open to trade.

Taken all together, there is ample empirical evidence suggesting that corporate income taxation affects multinational firms' decision-marking process. In the next section, I develop a general equilibrium model that is designed to explore corporate taxation as a determinant of trade and MP and to quantify its welfare implications.

[9] For a study on Germany MNEs, see Buettner and Ruf (2007), who obtain similar findings.

[10] Based on the answers from the respondents, the seven most important factors are Political stability of the country, Size of local market, Proximity to markets, Current and prospective macro-economic environment, Transparency/predictability of legal and regulatory framework, Quality of infrastructure, communications, etc., and Availability and quality of labor.

3 Model

In this section, I outline a multi-country general equilibrium framework of international trade and multinational production. The novel feature of this model is that, in addition to including the common trade and MP frictions from the literature, I introduce corporate income taxation as another determinant of firms' export and MP decisions.

3.1 Demand

Consider a world of N countries. The preferences of a representative consumer in country i is given by a CES utility function over a continuum of goods indexed by ω:

$$U_i = \left[\int_{\omega \in \Omega_i} q_i(\omega)^{\frac{\sigma-1}{\sigma}} d\omega \right]^{\frac{\sigma}{\sigma-1}}, \tag{1}$$

where Ω_i is the set of goods available to consumers in country i, $q_i(\omega)$ is the quantity of good ω consumed, and $\sigma > 1$ is the elasticity of substitution between any two goods. Utility maximization implies that the quantity demanded of good ω is

$$q_i(\omega) = \frac{p_i(\omega)^{-\sigma}}{P_i^{1-\sigma}} X_i, \tag{2}$$

where X_i is the total income in country i, $p_i(\omega)$ is the price of good ω, and P_i is the price index associated with equation (1):

$$P_i \equiv \left[\int_{\omega \in \Omega_i} p_i(\omega)^{1-\sigma} d\omega \right]^{\frac{1}{1-\sigma}}. \tag{3}$$

3.2 The Firm's Problem

Labor is the only factor of production. Country i is endowed with L_i units of inelastically supplied labor and a measure M_i of firms. Each firm produces a single good under monopolistic competition.

Firms can reach foreign markets via exporting, multinational production, or both. To keep notation consistent, I index a firm's country of origin by i, the production location by n, and the destination market by d. To serve market d, a firm from country i can either produce in country i and export to country d, build a production plant in country d and sell the good locally, or build a plant in country $n \neq i, d$ and export the good from country n to country d.

If the firm chooses to serve market d, it will incur a fixed marketing cost that is common to all firms entering market d, $w_d F_d$, where w_d is the wage in country d. In addition, there is an iceberg shipping cost τ_{dn}, where $\tau_{dn} \geq 1$ and $\tau_{dd} = 1$. If the firm chooses country $n \neq i$ as a potential production location, it will incur a firm-specific fixed MP cost in units of labor in country n, $w_n \varepsilon_{ni}(\omega)$, and an efficiency loss in the form of an iceberg cost $\gamma_{ni} \geq 1$, with $\gamma_{ii} = 1$. I assume that there is no fixed cost when setting up a plant at home, and that the firm can establish at most one plant in a country. The firm does not learn its productivity level in country n until it pays the fixed MP cost. If, after observing its productivity in country n, the firm decides to produce there, then the operating profits generated in n are subject to a corporate income tax levied by country n at rate t_n.[11] Tax revenue is rebated to consumers in country n through a lump-sum transfer, R_n.

Similar to Tintelnot (2017), I characterize the firm's problem by a two-stage optimization problem. First, given knowledge about a vector of fixed MP costs for all countries, the firm

[11] Fixed MP and marketing costs are not tax-deductible by assumption. These costs include intangible assets transferred between home-plant and plant-destination pairs as well as any searching and network construction costs incurred in the process of new plant setup and market entry. The intangible nature of these fixed costs makes them hard to be verified by tax authorities. Hence, it is reasonable to assume that they are not tax-deductible.

chooses a set of potential production locations in order to maximize its expected net profits. Second, after the firm pays fixed MP costs to the chosen countries, it observes a productivity level in each of them. Then, for each destination market, the firm chooses a production location that maximizes its after-tax operating profits. If the profits are enough to cover the fixed marketing costs, then the firm will serve the market.

I proceed by solving the second stage of the problem first.

3.2.1 Production Decision After Plant Location Set is Chosen

Let $\boldsymbol{\Delta}$ be the set that contains all possible sets of production locations, and denote by $\boldsymbol{\delta}^* \in \boldsymbol{\Delta}$ the set of locations that firm ω from country i has chosen for production. Assume that $\boldsymbol{\delta}^*$ contains $K \leq N$ countries. The firm learns its productivity z_k at each location $k = \{1, \ldots, K\}$. With constant returns to scale technologies, the unit cost of the firm to serve market d from country k is

$$c_{dki}(\omega) = \frac{\gamma_{ki}\tau_{dk}w_k}{z_k}. \tag{4}$$

For every market d, the firm chooses a production location from set $\boldsymbol{\delta}^*$ to serve d. Given the assumption on preferences and the market structure, if the firm produces in location k, the price it charges in d is $p_{dki}(\omega) = \overline{m}\, c_{dki}(\omega)$, where $\overline{m} \equiv \frac{\sigma}{\sigma-1}$ is the Dixit-Stiglitz markup. Monopolistic competition implies that operating profit has a share of $\frac{1}{\sigma}$ in sales, thus for a given market d, the firm's problem is to choose a production location to maximize its after-tax operating profits, which is given by:

$$\widetilde{\Pi}_{dki}(\omega) = (1 - t_k)\frac{1}{\sigma}\left(\frac{\overline{m}\, c_{dki}(\omega)}{P_d}\right)^{1-\sigma} X_d. \tag{5}$$

Since every firm is infinitesimal and takes prices indices and income as given, maximizing equation (5) is equivalent to minimizing the term $\frac{c_{dki}(\omega)}{(1-t_k)^{\frac{1}{\sigma-1}}}$, which I call the tax-adjusted unit cost.

Suppose that country n is the location that firm ω chooses to serve market d, the firm then compares the after-tax operating profits to the fixed cost of marketing and decides whether to serve market d. Specifically, the firm will serve market d if and only if $\widetilde{\Pi}_{dni}(\omega) \geq w_d F_d$, i.e., $\frac{c_{dni}(\omega)}{(1-t_n)^{\frac{1}{\sigma-1}}} \leq \overline{c}_d$, where

$$\overline{c}_d \equiv \left(\frac{X_d}{\sigma w_d F_d}\right)^{\frac{1}{\sigma-1}} \frac{P_d}{\overline{m}}. \tag{6}$$

The entry cut-off is destination-specific, meaning that all firms, regardless of their origin, face the same cost cutoff for market entry in country d.

Following ARRY, I assume that the vector of productivity levels for the locations in set $\boldsymbol{\delta} \in \boldsymbol{\Delta}$, $\mathbf{z}^{\boldsymbol{\delta}} = \{z_1, \ldots, z_K\}$, is a realization of a vector of random variables drawn from a multivariate Pareto distribution given by

$$\Pr(Z_1 \leq z_1, \ldots, Z_K \leq z_K \mid \boldsymbol{\delta}) = G_i(z_1, \ldots, z_K \mid \boldsymbol{\delta}) = 1 - \left[\sum_{k=1}^{K} \left(T_{ki} z_k^{-\theta}\right)^{\frac{1}{1-\rho}}\right]^{1-\rho}, \tag{7}$$

with support $z_k \geq (\widetilde{T}_i^{\boldsymbol{\delta}})^{1/\theta} \, \forall \, k \in \boldsymbol{\delta}$, where $\widetilde{T}_i^{\boldsymbol{\delta}} \equiv \left(\sum_{k=1}^{K} T_{ki}^{\frac{1}{1-\rho}}\right)^{1-\rho}$, $\rho \in [0,1)$, and $\theta > \max(1,\, \sigma - 1)$. The plant-origin specific scale parameter T_{ki} determines the location of the distribution. A bigger T_{ki} implies that a firm from country i is more likely to receive a higher productivity draw at location k. The shape parameter θ governs the dispersion of the productivity draws and the parameter ρ reflects the correlation between the draws. Specifically, if $\rho \to 1$, the productivity draws are perfectly correlated, and if $\rho = 0$, the productivities are drawn from the Pareto distribution $1 - \sum_{k=1}^{K} \left(T_{ki} z_k^{-\theta}\right)$. To ensure that there are firms from country i that will decide not to serve market d, I assume that the cut-off of the tax-adjusted unit cost, $\overline{c}_d$, is low enough. Formally, as in ARRY, I assume that $\overline{c}_d < \frac{\gamma_{ki}\tau_{dk}w_k}{(1-t_k)^{\frac{1}{\sigma-1}}}(\widetilde{T}_i^{\boldsymbol{\delta}})^{-1/\theta}\ \forall\, i, k, d$, and $\boldsymbol{\delta}$.

With the probabilistic representation of productivity levels, we can derive the probability that firm ω from country i will serve market d from country n with tax-adjusted unit cost $c \leq \overline{c}_d$ is

$$\Pr\left(\arg\min_k \frac{c_{dki}(\omega)}{(1-t_k)^{\frac{1}{\sigma-1}}} = n \cap \min_k \frac{c_{dki}(\omega)}{(1-t_k)^{\frac{1}{\sigma-1}}} = c \,\middle|\, \boldsymbol{\delta}\right) = \begin{cases} \psi_{dni}^{\boldsymbol{\delta}} \Psi_{di}^{\boldsymbol{\delta}} \theta c^{\theta-1}, & \text{if } n \in \boldsymbol{\delta} \\ 0 \qquad , & \text{otherwise} \end{cases}, \tag{8}$$

where

$$\Psi_{di}^{\boldsymbol{\delta}} \equiv \left[\sum_{k=1}^{K}\left(T_{ki}\left(\frac{\gamma_{ki}\tau_{dk}w_k}{(1-t_k)^{\frac{1}{\sigma-1}}}\right)^{-\theta}\right)^{\frac{1}{1-\rho}}\right]^{1-\rho}$$

and

$$\psi_{dni}^{\boldsymbol{\delta}} \equiv \left(\frac{T_{ni}\left(\frac{\gamma_{ni}\tau_{dn}w_n}{(1-t_n)^{\frac{1}{\sigma-1}}}\right)^{-\theta}}{\Psi_{di}^{\boldsymbol{\delta}}}\right)^{\frac{1}{1-\rho}},$$

while the probability that firm ω from country i will serve market d from country n is

$$\Pr\left(\arg\min_k \frac{c_{dki}(\omega)}{(1-t_k)^{\frac{1}{\sigma-1}}} = n \cap \min_k \frac{c_{dki}(\omega)}{(1-t_k)^{\frac{1}{\sigma-1}}} \leq \overline{c}_d \,\middle|\, \boldsymbol{\delta}\right) = \begin{cases} \psi_{dni}^{\boldsymbol{\delta}} \Psi_{di}^{\boldsymbol{\delta}} (\overline{c}_d)^{\theta}, & \text{if } n \in \boldsymbol{\delta} \\ 0 \qquad , & \text{otherwise} \end{cases} \tag{9}$$

The proof of equations (8) and (9) is presented in Appendix A.1. The expression in equation (9) readily delivers the following lemma:

Lemma 1 *(Intensive margin effect) For a given location set* $\boldsymbol{\delta}$ *such that* $i \in \boldsymbol{\delta}$*, the probability that a firm from country* i *will produce in country* $n \in \boldsymbol{\delta}$ *and serve market* d *is a decreasing* *function of the corporate tax rate imposed by country n, t_n.*

Proof: See Appendix A.2.

Lemma 1 suggests that, *ceteris paribus*, a firm from country i serving market d is less likely to produce in a country with a higher corporate tax rate. Since this translates to less investment directed to country n from country i, Lemma 1 is consistent with intensive margin effect of taxes found in the empirical studies, as we have seen in Section 2.

Next, I turn to the first stage of the firm's problem, in which conditional on the vector of fixed MP cost draws for all countries, the firm chooses a production location set that maximizes its expected net profits.

3.2.2 Choice of Production Location Sets

Using the probabilities derived in the second stage, for a given set $\boldsymbol{\delta} \in \boldsymbol{\Delta}$, the expected after-tax operating profits for firm ω from country i serving market d can be written as the weighted sum of the expected after-tax operating profits the firm would make from all locations in the location set, where the weights are the probabilities that the firm actually chooses the location to serve country d:

$$\begin{aligned}
\mathbb{E}\left[\widetilde{\Pi}_{di} \,\middle|\, \boldsymbol{\delta}\right] &= \sum_{n=1}^{K} \mathbb{E}\left[\widetilde{\Pi}_{dni}(\omega)\right] \cdot \Pr\left(\arg\min_{k\in\boldsymbol{\delta}} \frac{c_{dki}(\omega)}{(1-t_k)^{\frac{1}{\sigma-1}}} = n \cap \min_{k\in\boldsymbol{\delta}} \frac{c_{dki}(\omega)}{(1-t_k)^{\frac{1}{\sigma-1}}} \leq \bar{c}_d \,\middle|\, \boldsymbol{\delta}\right) \\
&= \sum_{n=1}^{K} \int_0^{\bar{c}_d} (1-t_n)\frac{1}{\sigma}\left(\overline{m}c(1-t_n)^{\frac{1}{\sigma-1}}\right)^{1-\sigma} P_d^{\sigma-1} X_d \psi_{dni}^{\boldsymbol{\delta}} \Psi_{di}^{\boldsymbol{\delta}} \theta c^{\theta-1}\, dc \\
&= \frac{\kappa}{\sigma}\Psi_{di}^{\boldsymbol{\delta}}\left(\frac{1}{\sigma w_d F_d}\right)^{\frac{\theta-\sigma+1}{\sigma-1}} P_d^{\theta} X_d^{\frac{\theta}{\sigma-1}},
\end{aligned} \tag{10}$$

where $\kappa \equiv \frac{\theta\overline{m}^{-\theta}}{\theta-\sigma+1}$ is a constant. The expected net profits of the firm choosing set $\boldsymbol{\delta}$ are the expected non-negative operating profits net of fixed marketing costs, minus fixed MP costs paid to the countries in the set:

$$\mathbb{E}_{\varepsilon}\left[\Pi_i(\omega) \mid \boldsymbol{\delta}\right] = \sum_d \left\{\max\left(\mathbb{E}\left[\widetilde{\Pi}_{di} \,\middle|\, \boldsymbol{\delta}\right] - w_d F_d,\ 0\right)\right\} - \sum_{k\in\boldsymbol{\delta}} w_k \varepsilon_{ki}(\omega). \tag{11}$$

Notice that the first term is the same for all firms from country i. Since firms do not differ in productivity levels *ex ante*, they form the same expectations with respect to the profits they would earn after paying the fixed MP costs associated with set $\boldsymbol{\delta}$. The only dimension of heterogeneity in this stage lies in the vector of fixed MP costs, which results in different location set choices across firms. Also, note that adding a location to a set has two counteracting effects on the expected net profits: on the one hand, it increases the first summation term in equation (11) since $\Psi_{di}^{\boldsymbol{\delta}}$ increases with the number of locations, but on the other hand, an additional location entails additional fixed MP costs.

For firm ω, the set of production locations that maximizes its expected net profits is a function of the vector of fixed MP cost draws $\boldsymbol{\varepsilon_i}(\omega) = \{\varepsilon_{1i}(\omega), \ldots, \varepsilon_{Ni}(\omega)\}$. Formally, in the first stage, the firm solves the following maximization problem:

$$\boldsymbol{\delta}^*(\boldsymbol{\varepsilon_i}(\omega)) = \arg\max_{\boldsymbol{\delta}\in\boldsymbol{\Delta}} \mathbb{E}_{\varepsilon}\left[\Pi_i(\omega) \mid \boldsymbol{\delta}\right]. \tag{12}$$

Lemma 2 *(Extensive margin effect) The probability that a firm chooses a location set containing country n over a location set that does not contain country n is a decreasing function of the corporate tax rate of country n, t_n.*

Proof: See Appendix A.2.

Lemma 2 reveals the role corporate income taxes play in this stage. Intuitively, suppose that country n raises its tax rate while other countries keep their rates fixed. Holding all other variables constant, the after-tax expected operating profits of the location sets

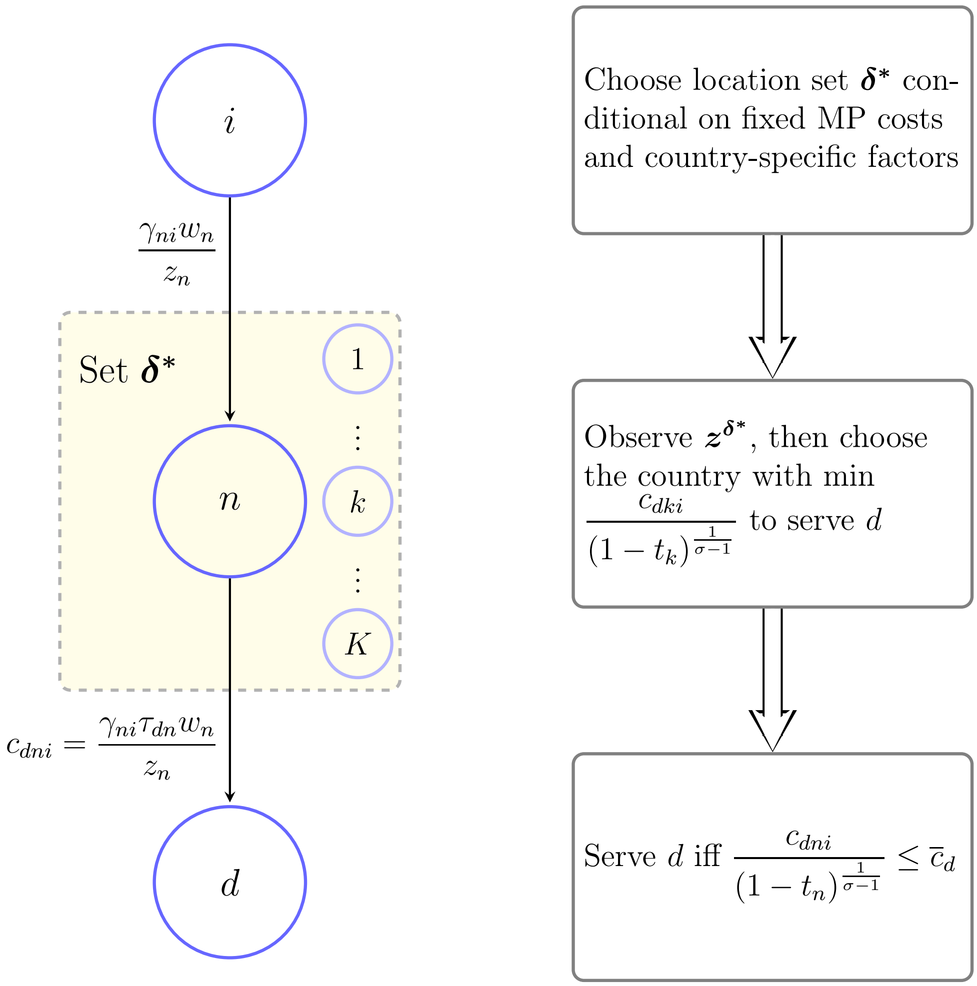

Figure 3: The Firm's Problem

containing country n decrease and firms now find it less profitable to choose such location sets. Consequently, marginal firms with high fixed cost draws for country n would switch to other location sets, likely the ones that do not contain country n. This corresponds to the extensive margin effect of taxes, as supported by evidence in Section 2.

As a summary of the firm's problem, Figure 3 depicts the decision-making process of a firm from country i serving market d.

3.3 Aggregation and Equilibrium

I proceed to aggregate up firms' decisions and characterize the equilibrium conditions. In order to derive aggregate variables in the model, I assume that the elements of the fixed MP costs, $\boldsymbol{\varepsilon_i}(\omega)$, are drawn independently across countries from a continuous distribution denoted by $H_i(\cdot)$.

The measure of firms from country i that choose production location set $\boldsymbol{\delta}$ is then the fraction of the total measure of firms in i for whom set $\boldsymbol{\delta}$ maximizes their expected net profits:

$$M_i^{\boldsymbol{\delta}} = M_i \int_{\boldsymbol{\varepsilon}} \mathbb{1}\left[\boldsymbol{\delta}^*(\boldsymbol{\varepsilon}) = \boldsymbol{\delta}\right] dH_i(\boldsymbol{\varepsilon}), \tag{13}$$

and the measure of firms from country i serving market d from country n, M_{dni}, is the measure of firms from i choosing location set $\boldsymbol{\delta}$ multiplied by the probability that these firms will serve market d from location n, summing across all possible location sets:

$$M_{dni} = \sum_{\boldsymbol{\delta}} M_i^{\boldsymbol{\delta}} \psi_{dni}^{\boldsymbol{\delta}} \Psi_{di}^{\boldsymbol{\delta}} (\overline{c}_d)^{\theta} = \left(\frac{X_d}{\sigma w_d F_d}\right)^{\frac{\theta}{\sigma-1}} \frac{P_d^{\theta}}{\overline{m}^{\theta}} \sum_{\boldsymbol{\delta}} M_i^{\boldsymbol{\delta}} \psi_{dni}^{\boldsymbol{\delta}} \Psi_{di}^{\boldsymbol{\delta}}. \tag{14}$$

The total sales from country n to market d by firms from i, X_{dni}, can be computed by integrating firm sales with the probability in equation (8):

$$\begin{aligned} X_{dni} &= \int_0^{\overline{c}_d} \sum_{\boldsymbol{\delta}} M_i^{\boldsymbol{\delta}} \psi_{dni}^{\boldsymbol{\delta}} \Psi_{di}^{\boldsymbol{\delta}} \theta c^{\theta-1} (\overline{m} c (1-t_n)^{\frac{1}{\sigma-1}})^{1-\sigma} P_d^{\sigma-1} X_d \, dc \\ &= \frac{\kappa}{1-t_n} \left(\frac{1}{\sigma w_d F_d}\right)^{\frac{\theta-\sigma+1}{\sigma-1}} P_d^{\theta} X_d^{\frac{\theta}{\sigma-1}} \sum_{\boldsymbol{\delta}} M_i^{\boldsymbol{\delta}} \psi_{dni}^{\boldsymbol{\delta}} \Psi_{di}^{\boldsymbol{\delta}}. \end{aligned} \tag{15}$$

Combining equations (14) and (15) yields

$$M_{dni} = (1-t_n) \frac{\theta-\sigma+1}{\sigma\theta} \frac{X_{dni}}{w_d F_d}. \tag{16}$$

Given the CES price index in equation (3), the pricing rule $p_{dni}(\omega) = \overline{m}\, c_{dni}(\omega)$, the probability in equation (8), and the cut-off in equation (6), the aggregate price index in country d, P_d, is given by

$$P_d = \left[\kappa \left(\frac{X_d}{\sigma w_d F_d} \right)^{\frac{\theta-\sigma+1}{\sigma-1}} \left(\sum_j \sum_l \sum_{\boldsymbol{\delta}} \frac{M_j^{\boldsymbol{\delta}} \psi_{dlj}^{\boldsymbol{\delta}} \Psi_{dj}^{\boldsymbol{\delta}}}{1-t_l} \right) \right]^{-\frac{1}{\theta}}. \tag{17}$$

Plugging equation (17) into equation (15), we obtain a gravity equation for the total sales from country n to market d by firms from country i:

$$X_{dni} = X_d \frac{\sum_{\boldsymbol{\delta}} M_i^{\boldsymbol{\delta}} \psi_{dni}^{\boldsymbol{\delta}} \Psi_{di}^{\boldsymbol{\delta}} / (1-t_n)}{\sum_j \sum_l \sum_{\boldsymbol{\delta}} M_j^{\boldsymbol{\delta}} \psi_{dlj}^{\boldsymbol{\delta}} \Psi_{dj}^{\boldsymbol{\delta}} / (1-t_l)}. \tag{18}$$

Note that not only do taxes have a direct effect on X_{dni}, but it also shapes the trade flows indirectly through its effect on M_i, ψ_{dni}, and Ψ_{di}.

Net profits earned by firms from country i, Π_i, are the total after-tax profits from sales X_{dni}, net of total fixed marketing costs and total fixed MP costs:

$$\Pi_i = \sum_d \sum_n \left[(1-t_n) \frac{1}{\sigma} X_{dni} - w_d F_d M_{dni} \right] - \sum_{\boldsymbol{\delta} \in \boldsymbol{\Delta}} M_i^{\boldsymbol{\delta}} \int_{\boldsymbol{\varepsilon}} \mathbb{1} \left[\boldsymbol{\delta}^*(\boldsymbol{\varepsilon}) = \boldsymbol{\delta} \right] \sum_{k \in \boldsymbol{\delta}} w_k \varepsilon_{ki} \, dH_i(\boldsymbol{\varepsilon}). \tag{19}$$

Total corporate tax revenue collected in country i, R_i, is a fraction t_i of the total operating profits generated by firms producing in country i:

$$R_i = \frac{t_i}{\sigma} \sum_d \sum_j X_{dij}. \tag{20}$$

Total labor income in country i is equal to the sum of the wages paid to production workers in country k by firms from all countries, the wages paid as fixed marketing costs by all firms serving country i, and the wages paid as fixed MP costs by all firms locating in country i:

$$w_i L_i = \underbrace{(1 - \frac{1}{\sigma}) \sum_d \sum_j X_{dij}}_{\text{production costs}} + \underbrace{w_i F_i \sum_n \sum_j M_{inj}}_{\text{fixed marketing costs}} + \underbrace{\sum_j \sum_{\boldsymbol{\delta} | i \in \boldsymbol{\delta}} M_j^{\boldsymbol{\delta}} \int_{\boldsymbol{\varepsilon}} \mathbb{1} \left[\boldsymbol{\delta}^*(\boldsymbol{\varepsilon}) = \boldsymbol{\delta} \right] w_i \varepsilon_{ij} \, dH_j(\boldsymbol{\varepsilon})}_{\text{fixed MP costs}} . \tag{21}$$

I assume that a representative agent from country i owns the domestic firms. The aggregate income in country i, X_i, is then the sum of the labor income, the profits earned by firms from i, and the corporate tax revenue:

$$X_i = w_i L_i + \Pi_i + R_i. \tag{22}$$

Equilibrium *Given the set of parameters* $\{\sigma, \theta, \rho, \tau_{dn}, \gamma_{ni}, T_{ni}, t_i, F_i, H_i(\boldsymbol{\varepsilon}), M_i, L_i\}$, *an equilibrium of the model is a set of wages* w_i, *price indices* P_i, *incomes* X_i, *quantity demanded* $q_i(\omega)$, *and location choices* $\boldsymbol{\delta}^*$ *such that*

(i) $q_i(\omega)$ *satisfies equation (2),*

(ii) $\boldsymbol{\delta}^*$ *is the solution to equation (12),*

(iii) P_i *satisfies equation (17),*

(iv) The labor market clearing condition, (21), holds, and

(v) X_i *satisfies equation (22).*

In the following section, I calibrate the key parameters of the model and solve for the general equilibrium outcomes.

4 Calibration

By assumption, a firm always has a plant in its home country, hence each firm has 2^{N-1} feasible location sets to choose from. As N grows, the equilibrium soon becomes computationally intensive to solve. To minimize the computational burden without jeopardizing delivery of the model's implications, I calibrate a three-country version of the model to Germany, Ireland, and the United States. The three countries are suitable for this exercise because they not only differ greatly in GDP and corporate tax rates, but also account for a large share of trade and multinational production. In this section, I describe the procedure I use to calibrate the key parameters to the general equilibrium outcomes of the model.

4.1 Parameters calibrated without solving the model

I set the measure of firms in country i, M_i, and the size of the labor force in country i, L_i, to be proportional to country i's population from the Penn World Tables. To be consistent with the time period of the trade and MP data, tax rates are targeted at the average statutory corporate tax rates in 1996-2001, a period before the worldwide tax cuts took place. The average statutory corporate tax rates for Germany, Ireland, and the United States are 50%, 34%, and 39%, respectively. Scale parameters of the multivariate Pareto distribution T_{ni} reflect the average productivity of firms from country i locating in country n. I assume that $T_{ni} = T_{nn}T_{ii}$, where T_{ii} is equal to country i's productivity (relative to the United States) measured by Hall and Jones (1999).

The multivariate Pareto shape parameter θ and correlation parameter ρ are calibrated to ARRY's estimates of the trade elasticity. ARRY show that the gravity equation implied by their model can be expressed as

$$\ln X_{dni} = \alpha_{ni} + \eta_{di} - \frac{\theta}{1-\rho} \ln \tau_{dn}, \tag{23}$$

where X_{dni} are the sales generated by the firms from country i that locate in country n and sell to country d, and α_{ni} and η_{di} are location-origin and destination-origin fixed effects, respectively. Consequently, the coefficient $-\frac{\theta}{1-\rho}$ is the elasticity of sales X_{dni} with respect to trade frictions between countries d and n. Using the BEA data on U.S. multinationals firms and data on tariff and other gravity controls, ARRY obtain an estimate of -10.9 for the trade elasticity $-\frac{\theta}{1-\rho}$. The gravity equation resulting from my model (equation (18)) yields the same estimating equation as in ARRY.[12] Hence, I calibrate $\frac{\theta}{1-\rho}$ to 10.9. To disentangle θ and ρ, ARRY solve their model and estimate an unrestricted gravity equation by regressing model-generated trade shares on calibrated trade costs and importing and exporting fixed effects. They show that for $\theta = 4$ and $\rho = 0.63$ (such that $\frac{\theta}{1-\rho} = 10.9$), the model-predicted unrestricted trade elasticity is 4.3, which is consistent with what the data implies. The model I calibrate only involves three countries, resulting in nine observations for the unrestricted gravity regression. Nonetheless, with the ARRY estimates for θ and ρ, I obtain an unrestricted trade elasticity of 4.2, suggesting that $\theta = 4$ and $\rho = 0.63$ are reasonable values for my calibration. Since $\theta > \sigma - 1$ needs to be satisfied, I choose $\sigma = 4$, which implies a mark-up of 33 percent.

4.2 Parameters determined in the equilibrium

The rest of the parameters to be determined include fixed marketing costs F_i, iceberg trade and MP costs τ_{dn} and γ_{ni}, and parameters for the distribution of fixed MP costs, $H_i(\boldsymbol{\varepsilon})$. Following the gravity literature, I parameterize bilateral trade and MP costs by the following

[12] Taking the log of equation (18) and rearranging terms would give rise to equation (23), where α_{ni} is a location-origin fixed effect given by $\alpha_{ni} = \ln\left(\left[T_{ni}(\gamma_{ni}w_n)^{-\theta}(1-t_n)^{-\frac{\theta-\sigma+1}{\sigma-1}}\right]^{\frac{1}{1-\rho}}\right)$, and η_{di} is a destination-origin fixed effect given by $\eta_{di} = \ln\left(X_d \frac{\sum_{\boldsymbol{\delta}} M_i^{\boldsymbol{\delta}}\left(\Psi_{di}^{\boldsymbol{\delta}}\right)^{\frac{-\rho}{1-\rho}}}{\sum_j \sum_l \sum_{\boldsymbol{\delta}} M_j^{\boldsymbol{\delta}} \psi_{dlj}^{\boldsymbol{\delta}} \Psi_{dj}^{\boldsymbol{\delta}}/(1-t_l)}\right)$.

functional form:

$$\ln \tau_{dn} = \beta^{\tau} + \ \beta^{\tau}_{dist}(\ln dist_{dn}) + \ \beta^{\tau}_{lang}\,(lang_{dn}) \qquad \text{for}\, d \neq n$$

$$\ln \gamma_{ni} = \beta^{\gamma} + \ \beta^{\gamma}_{dist}(\ln dist_{ni}) + \ \beta^{\gamma}_{lang}\,(lang_{ni}) \qquad \text{for}\, n \neq i,$$

where the variable *dist* measures the distance between the most populated cities in the two countries, and *lang* is a common language indicator, which takes the value one if the two countries share a common official language. Data on distance and language are available at the CEPII Gravity Database.

Fixed costs for domestic production are set to zero. For cross-border production, I assume that the distribution of fixed MP costs $H_i(\boldsymbol{\varepsilon})$ is a log-normal distribution with mean μ^{ε}_{ni} and standard deviation β^{ε}, where

$$\ln \mu^{\varepsilon}_{ni} = \beta^{\mu} + \ \beta^{\mu}_{dist}(\ln dist_{ni}) + \ \beta^{\mu}_{lang}\,(lang_{ni}) \qquad \text{for}\, n \neq i. \tag{24}$$

The parameterization produces a new set of parameters to be calibrated: $\{F_i,\ \{\boldsymbol{\beta^{\tau}}\},\ \{\boldsymbol{\beta^{\gamma}}\},\ \{\boldsymbol{\beta^{\mu}}\},\ \beta^{\varepsilon}\}$. In equilibrium, these parameters are jointly identified by a set of moments, which I describe below.

Fixed marketing costs F_i is crucial in determining the probability of becoming a domestic firm (where no export or MP occurs) from equations (9) and (13):

$$T_{ii}\left(\frac{w_i}{(1-t_i)^{\frac{1}{\sigma-1}}}\right)^{-\theta}\left(\frac{X_i}{\sigma w_i F_i}\right)^{\theta}\left(\frac{P_i}{\overline{\overline{m}}}\right)^{\theta}\int_{\boldsymbol{\varepsilon}} \mathbb{1}\left[\boldsymbol{\delta}^*(\boldsymbol{\varepsilon}) = \{i\}\right] dH_i(\boldsymbol{\varepsilon}). \tag{25}$$

Therefore, I calibrate F_i to match the share of non-exporters in the 2002 U.S. Census of Manufactures (0.82), as documented by Bernard et al. (2007)[13].

The vector of trade and MP parameters $\boldsymbol{\beta} = \{\{\boldsymbol{\beta^{\tau}}\},\ \{\boldsymbol{\beta^{\gamma}}\},\ \{\boldsymbol{\beta^{\mu}}\},\ \beta^{\varepsilon}\}$ determines trade

[13]Due to lack of systematic data across countries, I assume that this share is the same for all three countries.

and MP shares as well as the measure of foreign affiliates. In the model, trade shares are defined as the shares of income that consumers in country d spend on goods produced in country n,

$$s_{dn}^{TR} = \sum_i \frac{X_{dni}}{X_d}, \tag{26}$$

while MP shares are the shares of output produced by firms from country i in country n,

$$s_{ni}^{MP} = \sum_d \frac{X_{dni}}{Y_n}, \tag{27}$$

where $Y_n \equiv \sum_d \sum_i X_{dni}$ is the total output produced in country n. For the data counterparts, I use trade data from the World Input-Output Database and multinational production data from Ramondo et al. (2015) (henceforth RRT). Both are averages across the years 1996 to 2001. To back out the standard deviation of fixed MP cost draws, ideally I need data on the measure of firms choosing a given location set. Due to data limitation, I instead use data on the number of foreign affiliates provided by RRT. Specifically, for each origin country, I construct a ratio of foreign affiliates by computing the relative number of affiliates located in the other two countries.[14] Intuitively, this ratio is informative as it translates the dispersion in fixed cost draws into the relative number of affiliates across countries.

Table 2 summarizes the parameters as well as the moments targeted in the calibration.

4.3 Algorithm

As described above, the remaining exercise is to calibrate the set of parameters $\{F_i,\ \{\boldsymbol{\beta^\tau}\},\ \{\boldsymbol{\beta^\gamma}\},\ \{\boldsymbol{\beta^\mu}\},\ \beta^\varepsilon\}$ while solving for the equilibrium outcomes $\{w_i,\ P_i,\ X_i\}$. I develop a three-loop iterative procedure to achieve this goal.

[14] I divide the larger number of foreign affiliates by the smaller number of foreign affiliates, so that the ratio is greater than 1.

Table 2: Summary of Calibrated Parameters

Parameters	Description	Targets/Source
M_i, L_i	Measure of firms, size of labor force	Penn World Tables
t_i	Statutory tax rates	Flaaen (2017)
T_{ni}	Average productivity	Hall and Jones (1999)
θ	Dispersion in firm productivity	ARRY
ρ	Correlation between location productivities	ARRY
σ	Elasticity of substitution	Mark-up = 33%
F_i	Fixed marketing costs	Share of domestic firms = 0.8
	Coefficients of gravity variables	Trade shares/WIOD
$\boldsymbol{\beta}$	in trade and MP costs and	MP shares/RRT
	dispersion in fixed MP cost draws	Ratio of foreign affiliates/RRT

Inner Loop Given a set of parameters $\{F_i, \{\boldsymbol{\beta^\tau}\}, \{\boldsymbol{\beta^\gamma}\}, \{\boldsymbol{\beta^\mu}\}, \beta^\varepsilon\}$ and guesses for wages, prices and income $\{w_i, P_i, X_i\}$, the inner loop solves for the equilibrium price indices P_i. Specifically, I compute $\psi^{\boldsymbol{\delta}}_{dni}$, $\Psi^{\boldsymbol{\delta}}_{di}$, and $M^{\boldsymbol{\delta}}_i$ for all d, n, i, and $\boldsymbol{\delta}$, which I plug into equation (17) to update the price indices. I continue the process until the updated P_i is the same as the input.

Middle Loop In the middle loop, I solve for the equilibrium wages w_i relative to the United States (U.S. labor is the numeraire) and income X_i. Given the exogenous parameters, the equilibrium price indices P_i solved in the inner loop, and the input wages and income used in the inner loop, I calculate aggregate sales (equation (18)), measure of firms (equation (16)), net profits (equation (19)), and total corporate tax revenue (equation 20)). Then, I update wages and income using the market clearing conditions (equations (21) and (22)) and feed them back to the inner loop to update P_i. I iterate over w_i and X_i until they converge.

Outer Loop The outer loop iterates over guesses of $\{F_i, \{\boldsymbol{\beta^\tau}\}, \{\boldsymbol{\beta^\gamma}\}, \{\boldsymbol{\beta^\mu}\}, \beta^\varepsilon\}$ such that (1) the probability of becoming a domestic firm is 0.82, (2) trade and MP shares are the same as their data counterparts, and (3) the ratios of foreign affiliates exactly match the data. More precisely, I increase the value of F_i if the model-predicted share of domestic firms is larger than 0.82. I also ensure that with the calibrated F_i, the market-entry cutoff $\overline{c}_i$ is low enough so that some firms would choose not to serve market i. The parameter β^{ε} governs the dispersion of the fixed MP cost draws: a larger β^{ε} implies more dispersion. Loosely speaking, I increase the value of β^{ε} if the ratios of foreign affiliates are small for all three countries.

5 Quantitative Analysis

The calibrated model allows me to perform a series of quantitative exercises to shed light on the welfare implications of corporate income taxation through its distortion on international trade and multinational production.

5.1 Nash Corporate Tax Rates

To begin with, I compute the Nash statutory corporate tax rates for Germany, Ireland, and the United States. The outcome constitutes an equilibrium of non-cooperative tax competition. Given tax rates in the other two countries, each country chooses a tax rate non-cooperatively in order to maximize its representative agent's welfare, defined as her real income.

I first demonstrate the unilateral optimal tax rates for the three countries. The blue solid line in Figure 4 illustrates how welfare varies with tax rates in Ireland, holding tax rates in Germany and the United States fixed. I normalize welfare to 1 when tax rate in Ireland is 0%. Under the calibrated model (henceforth the Baseline model), there is an interior optimal tax rate for Ireland. This is because both real wages and corporate profits decrease with tax rates while real tax revenue is hump-shaped with respect to tax rates.[15] As tax rate

[15]The hump for real tax revenue occurs at very high tax rates (around 80%).

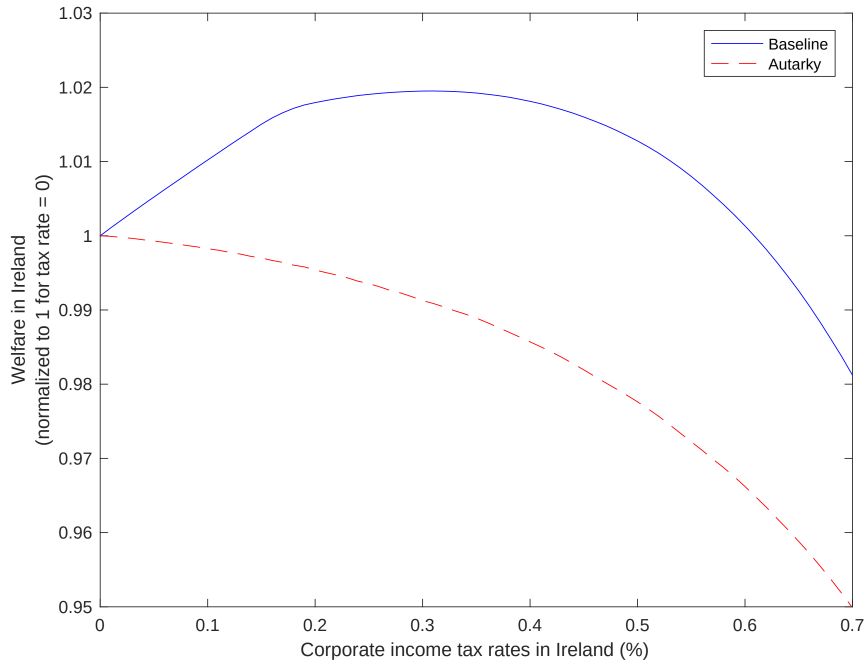

Figure 4: Optimal Corporate Tax Rates in Ireland

Notes: This figure depicts how the equilibrium welfare in Ireland (the y-axis) varies with corporate income tax rate in Ireland (the x-axis), holding tax rates in Germany and the United States fixed at the baseline level. The blue solid line is for the Baseline model, and the red dashed line is for autarky. For each case, welfare is normalized to 1 when tax rate is 0%.

increases, the increase in tax revenue dominates the decrease in profits and wages up to a point where the reverse happens. Intuitively, with the possibility of MP, local governments are able to extract some of the profits of foreign firms. On the one hand, governments would pursue a high tax rate to increase tax revenue, but on the other hand, a high tax rate not only would deter MNEs from producing in the country but also would cause prices to rise and real wages to drop. This tradeoff determines the positive optimal tax rate in the Baseline model.

As a comparison, the red dashed line in Figure 4 reveals the optimal tax rate for Ireland in autarky, a situation where both trade and multinational production are prohibited. Keep in mind that at zero corporate tax rate, welfare in Ireland decreases by 20% when moving

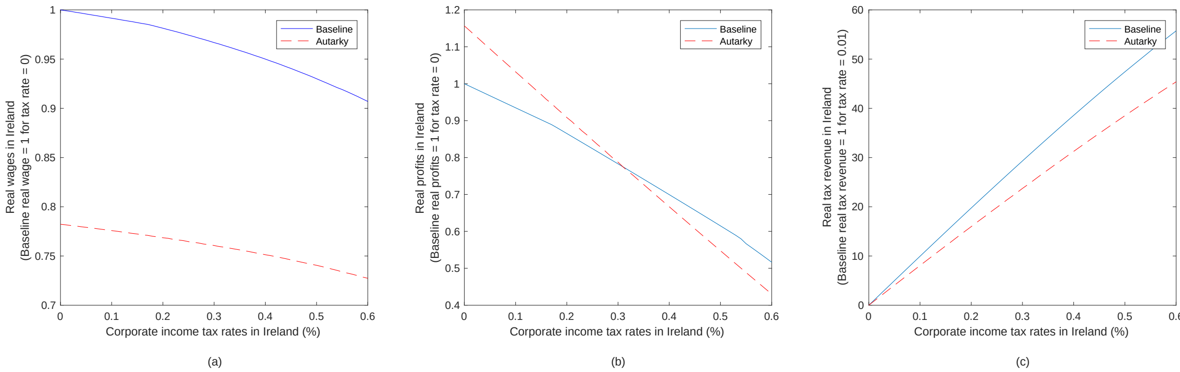

Figure 5: The Effect of Tax Rates on Real Wages, Profits, and Tax Revenue in Ireland

Notes: This figure depicts how the equilibrium (a) real wages (b) real profits, and (c) real tax revenue in Ireland vary with corporate income tax rates in Ireland, holding tax rates in Germany and the United States fixed at the baseline level. The blue solid lines are for the Baseline model, and the red dashed lines are for autarky. Baseline values in (a) and (b) are normalized to 1 when tax rate is 0% in Ireland and baseline real tax revenue is normalized to 1 when tax rate is 1% in Ireland.

from the Baseline model to autarky. However, for presentation purpose, I normalize welfare to 1 when tax rate is 0% in autarky. From Figure 4 we can see that in autarky welfare is monotonically decreasing as tax rate increases, and the optimal tax rate for Ireland is 0%. Without the possibility of MP, firms can only produce domestically. A positive tax rate is detrimental as it generates little tax revenue at the cost of a large distortion to firms' market entry. Compared to the baseline scenario, I find that in autarky (i) real wages are lower and decrease at a slower rate as tax rate increases, (ii) real profits are higher when tax rates are low but decrease at a faster rate, and (iii) real tax revenue is lower and increases at a slower rate as tax rate increases. The three findings are shown graphically in Figure 5. The sharp decrease in profits and slow increase in revenue determine the zero optimal tax rate in autarky.

Additional figures for Germany and the United States are included in Appendix B. The optimal tax rates for these two countries are also positive in the Baseline model and zero in autarky.

Motivated by the existence of interior optimal tax rates in the Baseline model, I adapt an iterative algorithm to solve for the Nash tax rates. Formally, the algorithm proceeds as follows:

Step 1: Fix tax rate in the United States at the initial level. First, compute the optimal tax rate in Ireland given a guess of Germany's optimal tax rate, then compute Germany's optimal tax rate given Ireland's optimal tax rate, and so on, until there is no incentive for either Ireland or Germany to deviate from the current optimal tax rate.

Step 2: Compute optimal tax rate for the United States given the other two countries' optimal tax rates. If the U.S. optimal tax rate is the same as the one from the previous step, then stop. If not, update the optimal tax rate for the United States and repeat Step 1.

Table 3 reports the result. The first column recalls the tax rates targeted in the calibration (henceforth Baseline tax rates). With the Baseline model, I compute the Nash equilibrium tax rates and the associated welfare changes when countries move from the Baseline tax rates to the Nash tax rates. Results are shown in columns 2 and 3. All three countries would choose tax rates lower than the Baseline if they were in the non-cooperative tax competition. Ireland would reduce its tax rate slightly, from 34% to 31%, whereas Germany and the United States would incur large reductions in tax rates, by 9 percentage points and 11 percentage points, respectively. As countries reduce their tax rates, firms which previously did not meet the cost cutoff for market entry are now able to overcome the hurdle. Since the United States and Germany are endowed with larger measure of firms, they would reduce tax rates more than Ireland. In terms of changes in welfare, all three countries would experience welfare gains when moving to the Nash tax rates. Germany would benefit the most from the tax competition, seeing a 0.61% increase in welfare. Welfare in Ireland and the United States would increase by 0.28% and 0.46%, respectively. Despite the small tax rate change, Ireland

Table 3: Nash Corporate Tax Rates under Baseline Model

	Baseline tax rates	Nash tax rates	ΔWelfare (%)	ΔInward MP Share (p.p)	ΔImport Share (p.p)
Germany	50	41	0.61	0.42	-0.11
Ireland	34	31	0.28	-0.11	-0.31
United States	39	28	0.46	0.06	-0.02

Notes: Entries under *Baseline* and *Nash* are statutory corporate tax rates (in percent) in the Baseline and Nash equilibria, respectively; entries under Δ *Welfare* are counterfactual welfare changes (in percent) when moving from the Baseline tax rates to the Nash tax rates. Entries under Δ*Inward MP Share* are the changes in inward MP share (in percentage point), defined as the share of foreign affiliates' output in total output produced in the country. Entries under Δ*Import Share* are the changes in import share (in percentage point), defined as the share of imports in total absorption.

would still experience a moderate welfare gain, suggesting that welfare is relatively elastic to tax changes in Ireland. In the last two columns of Table 3, I compute the change in inward MP shares and the change in import shares. Recall that the inward MP share is defined as the share of foreign affiliates' output in total output produced in the country. The import share is defined as the share of imports in total absorption. The reduction in tax rates makes MP relatively more attractive to firms, which leads to a decrease in import shares everywhere. Inward MP share increases sharply in Germany while decreases in Ireland, implying that the large tax cut in Germany weakens Ireland's comparative advantage in attracting firms with low tax rates.

5.2 Elimination of Corporate Taxes

I proceed by investigating the consequences of eliminating corporate income taxes. As shown in column 1 of Table 4, if all countries set corporate tax rates to zero, welfare would decrease by 4.92%, 1.43%, and 4.05% in Germany, Ireland, and the United States, respectively. Moving to zero tax rates, the decrease in tax revenue dominates the increase in profits

Table 4: Consequences of Elimination of Corporate Tax

	ΔWelfare (%)	ΔInward MP Share (p.p)	ΔImport Share (p.p)
Germany	-4.92	5.12	-1.10
Ireland	-1.43	2.12	7.14
United States	-4.05	-0.08	2.28

Notes: Entries under Δ*Welfare* are the welfare changes (in percent) when countries move from the Baseline tax rates to zero tax rates. Entries under Δ*Inward MP Share* are the changes in inward MP share (in percentage point), defined as the share of foreign affiliates' output in total output produced in the country. Entries under Δ*Import Share* are the changes in import share (in percentage point), defined as the share of imports in total absorption.

and wages. All countries are worse off without corporate tax revenue, especially the ones for which taxation constitutes a large portion of total income.

In columns 2 and 3, I show the effect of eliminating corporate taxes on inward MP shares and import shares. When corporate taxes are eliminated, inward MP shares increase in Germany and Ireland while decreasing slightly in the United States. Without the tax constraint, firms are more free to locate production in foreign countries. However, in this scenario, Ireland totally loses its tax-induced comparative advantage, which results in a larger increase in its equilibrium real wage compared to the other two countries. The general equilibrium wage effect leads firms from Germany and United States to favor exporting to Ireland, in order to avoid paying the high wage to production workers in Ireland. As for Germany, the effect of tax elimination is straightforward: firms would choose MP over exporting because of the zero tax rate and low wage. The United States would experience a decrease in inward MP share and an increase in import share. This is driven by the German firms, since they now find the U.S wage to be higher and would reduce MP and increase exports.

Table 5: Gains from MP, Trade, and Openness

	MP	Trade	Openness
Germany	1.0169	1.0125	1.0371
Ireland	1.0508	1.1011	1.2334
United States	1.0040	1.0050	1.0103

Notes: Entries are computed by dividing the welfare from the calibrated model by the welfare from the counterfactual world, where MP, trade, and both MP and trade are prohibited, respectively.

5.3 Welfare gains from MP, Trade, and Openness

I continue the quantitative analysis by conducting a series of counterfactual exercises to highlight the importance of different forces in the model to welfare analysis. Table 5 summarizes the welfare gains when countries move from the counterfactual world to the calibrated world.

First, I quantify welfare gains from MP. To do so, I divide the welfare from the Baseline model by the welfare from the model without multinational production. The entries in column 1 show that welfare gains from MP are the largest in Ireland, moderate in Germany, and the smallest in the United States. This result is comparable to Tintelnot (2017), where gains from MP are 1.013, 1.044, and 1.008 for Germany, Ireland, and the United States, respectively. I then shut down trade and compute welfare gains from trade in the same manner. Similar to MP, Ireland gains the most with the possibility to trade among the three countries. Finally, in column 3, I report the welfare gains from openness by considering MP and trade together. Since both channels are shut down in autarky, it is not surprising to see that gains from openness are more substantial than gains from MP and gains from trade alone. Consistent with the literature, I find that small countries benefit more from MP, trade, and openness.

6 Conclusion

The determinants and consequences of multinational production have been widely studied. In this paper, I focus on one particular determinant of multinational production, i.e., corporate income taxation. The importance of corporate taxes to multinational firms have been explored extensively in the public economics literature. Although it seems natural to investigate in the context of international economics, existing quantitative studies neglect corporate taxation when modeling multinational firms' decisions.

This paper is the first to examine the channels through which corporate income taxation affects multinational production under a general equilibrium framework, which encompasses international trade, multinational production, and corporate taxation. The model accounts for both fixed and variable costs of international trade and multinational production while maintaining tractability.

I calibrate the model and conduct a series counterfactual exercises. Computing Nash equilibrium tax rates using an iterative algorithm reveals that large countries would experience larger tax cuts in order to trigger market entry of marginal firms. All three countries gain from the tax competition. In a second exercise where I eliminate corporate income taxes, I find that all countries are worse off if they set zero tax rates. Ireland loses its comparative advantage in attracting firms, and Germany would see a large increase in inward MP. Lastly, I quantify gains from MP, trade, and openness. Consistent with the literature, the model predicts that small countries benefit more from an open regime than large countries.

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Appendix A: Proofs and Results

A.1. Proof of Equations (8) and (9)

Proof: Assuming that the productivity vector $\mathbf{z}$ follows the distribution specified in equation (7) and that $c_{dki} \leq (\gamma_{ki}\tau_{dk}w_k)(\widetilde{T}_i^{\boldsymbol{\delta}})^{-1/\theta}\ \forall\, k$, it is straightforward to show that

$$\begin{aligned}
&\Pr\left(\frac{C_{d1i}}{(1-t_1)^{\frac{1}{\sigma-1}}} \geq c_{d1i}, \ldots, \frac{C_{dKi}}{(1-t_K)^{\frac{1}{\sigma-1}}} \geq c_{dKi} \,\middle|\, \boldsymbol{\delta}\right) \\
&= \Pr\left(Z_1 \leq \frac{\gamma_{1i}\tau_{d1}w_1}{(1-t_1)^{\frac{1}{\sigma-1}}c_{d1i}}, \ldots, Z_K \leq \frac{\gamma_{Ki}\tau_{dK}w_K}{(1-t_K)^{\frac{1}{\sigma-1}}c_{dKi}} \,\middle|\, \boldsymbol{\delta}\right) \\
&=1 - \left[\sum_{k=1}^{K}\left(T_{ki}\left(\frac{\gamma_{ki}\tau_{dk}w_k}{(1-t_k)^{\frac{1}{\sigma-1}}c_{dki}}\right)^{-\theta}\right)^{\frac{1}{1-\rho}}\right]^{1-\rho}. \qquad \text{(A.1)}
\end{aligned}$$

Since

$$\begin{aligned}
&\Pr\left(\frac{C_{d1i}}{(1-t_1)^{\frac{1}{\sigma-1}}} \geq c_{d1i}, \ldots, \frac{C_{dni}}{(1-t_n)^{\frac{1}{\sigma-1}}} = c_{dni}, \ldots, \frac{C_{dKi}}{(1-t_K)^{\frac{1}{\sigma-1}}} \geq c_{dKi} \,\middle|\, \boldsymbol{\delta}\right) \\
&= -\frac{\partial\ \Pr\left(\frac{C_{d1i}}{(1-t_1)^{\frac{1}{\sigma-1}}} \geq c_{d1i}, \ldots, \frac{C_{dni}}{(1-t_n)^{\frac{1}{\sigma-1}}} \geq c_{dni}, \ldots, \frac{C_{dKi}}{(1-t_K)^{\frac{1}{\sigma-1}}} \geq c_{dKi} \,\middle|\, \boldsymbol{\delta}\right)}{\partial\, c_{dni}},
\end{aligned}$$

from equation (A.1) we have that

$$\begin{aligned}
&\Pr\left(\frac{C_{d1i}}{(1-t_1)^{\frac{1}{\sigma-1}}} \geq c_{d1i}, \ldots, \frac{C_{dni}}{(1-t_n)^{\frac{1}{\sigma-1}}} = c_{dni}, \ldots, \frac{C_{dKi}}{(1-t_K)^{\frac{1}{\sigma-1}}} \geq c_{dKi} \,\middle|\, \boldsymbol{\delta}\right) \\
&=\theta\left[\sum_{k=1}^{K}\left(T_{ki}\left(\frac{\gamma_{ki}\tau_{dk}w_k}{(1-t_k)^{\frac{1}{\sigma-1}}c_{dki}}\right)^{-\theta}\right)^{\frac{1}{1-\rho}}\right]^{-\rho}\left(T_{ni}\left(\frac{\gamma_{ni}\tau_{dn}w_n}{(1-t_n)^{\frac{1}{\sigma-1}}}\right)^{-\theta}\right)^{\frac{1}{1-\rho}} c_{dni}^{\frac{\theta}{1-\rho}-1}.
\end{aligned}$$

If $c < (\gamma_{ki}\tau_{dk}w_k)(\widetilde{T}_i^{\boldsymbol{\delta}})^{-1/\theta}\ \forall\, k$, then the probability that a firm from country i will serve market d from country $n \in \boldsymbol{\delta}$ at tax-adjusted cost c is

$$
\begin{aligned}
&\Pr\left(\arg\min_{k\in\boldsymbol{\delta}} \frac{c_{dki}}{(1-t_k)^{\frac{1}{\sigma-1}}} = n \cap \min_{k\in\boldsymbol{\delta}} \frac{c_{dki}}{(1-t_k)^{\frac{1}{\sigma-1}}} = c \,\middle|\, \boldsymbol{\delta}\right)\\
=&\Pr\left(\frac{C_{d1i}}{(1-t_1)^{\frac{1}{\sigma-1}}} \geq c, \ldots, \frac{C_{dni}}{(1-t_n)^{\frac{1}{\sigma-1}}} = c, \ldots, \frac{C_{dKi}}{(1-t_K)^{\frac{1}{\sigma-1}}} \geq c \,\middle|\, \boldsymbol{\delta}\right)\\
=&\theta\left[\sum_{k=1}^{K}\left(T_{ki}\left(\frac{\gamma_{ki}\tau_{dk}w_k}{(1-t_k)^{\frac{1}{\sigma-1}}c}\right)^{-\theta}\right)^{\frac{1}{1-\rho}}\right]^{-\rho}\left(T_{ni}\left(\frac{\gamma_{ni}\tau_{dn}w_n}{(1-t_n)^{\frac{1}{\sigma-1}}}\right)^{-\theta}\right)^{\frac{1}{1-\rho}} c^{\frac{\theta}{1-\rho}-1}\\
=&\psi_{dni}^{\boldsymbol{\delta}}\Psi_{di}^{\boldsymbol{\delta}}\theta c^{\theta-1}. \qquad \text{(A.2)}
\end{aligned}
$$

Given the assumption that $\overline{c}_d < \frac{\gamma_{ni}\tau_{dn}w_n}{(1-t_k)^{\frac{1}{\sigma-1}}}(\widetilde{T}_i^{\boldsymbol{\delta}})^{-1/\theta}\ \forall\, i, n, d$ and $\boldsymbol{\delta}$, we can derive the probability that a firm from country i will serve market d from n by integrating equation (A.2) over c from 0 to $\overline{c}_d$:

$$
\begin{aligned}
\Pr\left(\arg\min_{k\in\boldsymbol{\delta}} \frac{c_{dki}}{(1-t_k)^{\frac{1}{\sigma-1}}} = n \cap \min_{k\in\boldsymbol{\delta}} \frac{c_{dki}}{(1-t_k)^{\frac{1}{\sigma-1}}} \leq \overline{c}_d \,\middle|\, \boldsymbol{\delta}\right) &= \psi_{dni}^{\boldsymbol{\delta}}\Psi_{di}^{\boldsymbol{\delta}}\theta\int_0^{\overline{c}_d} c^{\theta-1}dc\\
&= \psi_{dni}^{\boldsymbol{\delta}}\Psi_{di}^{\boldsymbol{\delta}}(\overline{c}_d)^{\theta}.
\end{aligned}
$$

■

A.2. Proof of Lemmas

Lemma 1 *(Intensive margin effect) For a given location set $\boldsymbol{\delta}$ such that $i \in \boldsymbol{\delta}$, the probability that a firm from country i will produce in country $n \in \boldsymbol{\delta}$ and serve market d is a decreasing function of the corporate tax rate imposed by country n, t_n.*

Proof: Taking the partial derivative of equation (9) with respect to t_n for $n \in \boldsymbol{\delta}$, we have that

$$\frac{\partial \psi_{dni}^{\boldsymbol{\delta}} \Psi_{di}^{\boldsymbol{\delta}} (\overline{c}_d)^\theta}{\partial t_n} = \frac{\partial \left(T_{ni} \left(\frac{\gamma_{ni}\tau_{dn}w_n}{(1-t_n)^{\frac{1}{\sigma-1}}} \right)^{-\theta} \right)^{\frac{1}{1-\rho}} \left[\sum_{k=1}^{K} \left(T_{ki} \left(\frac{\gamma_{ki}\tau_{dk}w_k}{(1-t_k)^{\frac{1}{\sigma-1}}} \right)^{-\theta} \right)^{\frac{1}{1-\rho}} \right]^{-\rho} (\overline{c}_d)^\theta}{\partial t_n}$$

$$= \frac{\theta (\overline{c}_d)^\theta \left(T_{ni} \left(\gamma_{ni}\tau_{dn}w_n \right)^{-\theta} \right)^{\frac{1}{1-\rho}}}{(\sigma-1)(1-\rho)} \left[\sum_{k=1}^{K} \left(T_{ki} \left(\frac{\gamma_{ki}\tau_{dk}w_k}{(1-t_k)^{\frac{1}{\sigma-1}}} \right)^{-\theta} \right)^{\frac{1}{1-\rho}} \right]^{-\rho-1} (1-t_n)^{\frac{\theta}{(\sigma-1)(1-\rho)}-1}$$

$$\cdot \left\{ -\sum_{k=1}^{K} \left(T_{ki} \left(\frac{\gamma_{ki}\tau_{dk}w_k}{(1-t_k)^{\frac{1}{\sigma-1}}} \right)^{-\theta} \right)^{\frac{1}{1-\rho}} + \rho (1-t_n)^{\frac{\theta}{(\sigma-1)(1-\rho)}} \left(T_{ni} \left(\gamma_{ni}\tau_{dn}w_n \right)^{-\theta} \right)^{\frac{1}{1-\rho}} \right\}$$

Since the terms outside the big curly brackets are all positive, to determine the sign of the partial derivative, we only need to know the sign of the term inside the big curly brackets, which, after some rearrangement, becomes

$$\rho \left(T_{ni} \left(\frac{\gamma_{ni}\tau_{dn}w_n}{(1-t_n)^{\frac{1}{\sigma-1}}} \right)^{-\theta} \right)^{\frac{1}{1-\rho}} - \sum_{k=1}^{K} \left(T_{ki} \left(\frac{\gamma_{ki}\tau_{dk}w_k}{(1-t_k)^{\frac{1}{\sigma-1}}} \right)^{-\theta} \right)^{\frac{1}{1-\rho}} .$$

Given that $\rho \in [0, 1)$ and that $n \in \{1, \ldots, K\}$, it is clear that this term is negative. ■

Lemma 2 *(Extensive margin effect) The probability that a firm chooses a location set containing country n over a location set that does not contain country n is a decreasing function of the corporate tax rate of country n, t_n.*

Proof: The probability that a firm chooses a location set containing country n over a location set that does not contain country n is

$$\begin{aligned}
&\Pr\left\{\mathbb{E}_{\varepsilon}\left[\Pi(\omega)\,|\,\boldsymbol{\delta}, n\in\boldsymbol{\delta}\right] \geq \mathbb{E}_{\varepsilon}\left[\Pi(\omega)\,|\,\boldsymbol{\delta'}, n\notin\boldsymbol{\delta'}\right]\right\} \\
=&\Pr\left\{\max\left[\sum_{d}\left(\mathbb{E}\left[\widetilde{\Pi}_{di}(\omega)\,\middle|\,\boldsymbol{\delta}, n\in\boldsymbol{\delta}\right]-w_dF_d\right),\ 0\right]-\sum_{k\in\boldsymbol{\delta}}w_k\varepsilon_{ki}\right. \\
&\left.\geq \max\left[\sum_{d}\left(\mathbb{E}\left[\widetilde{\Pi}_{di}(\omega)\,\middle|\,\boldsymbol{\delta'}, n\notin\boldsymbol{\delta'}\right]-w_dF_d\right),\ 0\right]-\sum_{l\in\boldsymbol{\delta'}}w_l\varepsilon_{li}\right\}.
\end{aligned}$$

The term after the "$\geq$" sign is not affected by the tax rate in country n since $n \notin \boldsymbol{\delta'}$. The term before the "$\geq$" sign, however, decreases with the tax rate in country n since

$$\mathbb{E}_{\varepsilon}\left[\Pi(\omega)\,|\,\boldsymbol{\delta}, n\in\boldsymbol{\delta}\right] = \frac{\kappa}{\sigma}\Psi_{di}^{\boldsymbol{\delta}}\left(\frac{1}{\sigma w_d F_d}\right)^{\frac{\theta-\sigma+1}{\sigma-1}} P_d^{\theta} X_d^{\frac{\theta}{\sigma-1}}$$

and $\frac{\partial \Psi_{di}^{\boldsymbol{\delta}}}{\partial t_n} < 0$. Hence, the overall probability is a decreasing function of the tax rate imposed by country n, t_n. ■

Appendix B: Additional Tables and Figures

B.1. Table of Regression Results for Figure 2

Dependent variable: ΔInward MP shares

	(1)	(2)	(3)
ΔTax rate	-0.76**	-0.72**	-0.69*
	(0.31)	(0.34)	(0.34)
ΔGDP		-0.0008	-0.0017
		(0.0013)	(0.0015)
ΔTariff			-1.63**
			(0.58)
No. Obs	23	23	23
R^2	0.27	0.27	0.30

Source: Tax rate data is from Flaaen (2017). GDP and tariff data are from the World Development Indicators (WDI).

Notes: *** p < 0.01, ** p < 0.05, * p < 0.1.

B.2. Optimal Tax Rates in Germany and the United States

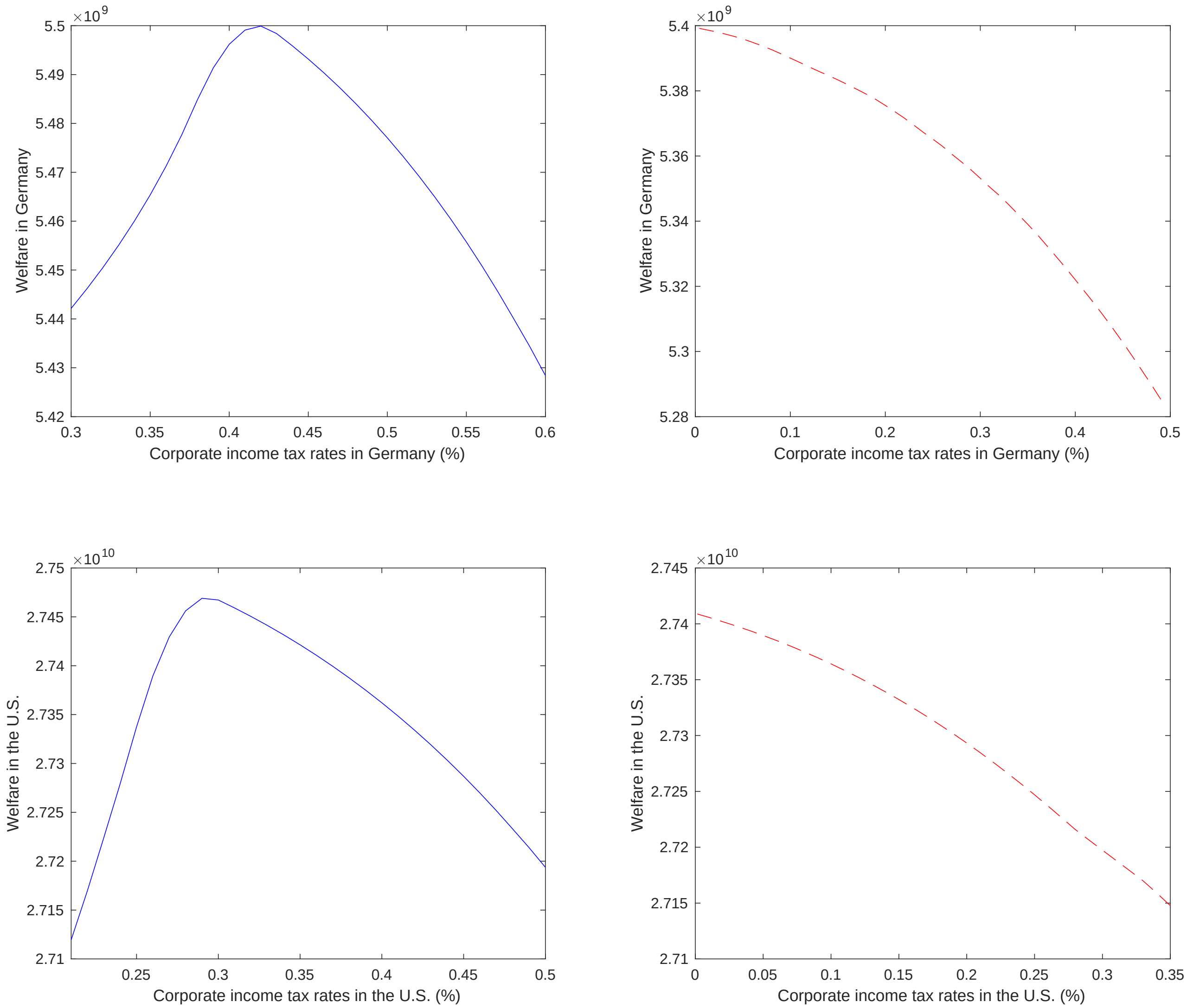

Figure 6: Optimal Corporate Tax Rates in Germany and the United States
Notes: This figure depicts how the equilibrium welfare in Germany (top) and the United States (bottom) vary with their own corporate income tax rates, holding tax rates in the other two countries fixed at the baseline level. The blue solid line is for the Baseline model and the red dashed line is for autarky.