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 U.S. would undercut Ireland in the tax competition, i.e., the non-cooperative Nash equilibrium. Welfare analysis reveals that Ireland would lose in the tax competition, but all countries could gain if corporate taxation is eliminated everywhere.

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 imports and exports, but they also operate internationally and comprise roughly a quarter of world GDP (UNCTAD (1996, 2000)).\footnote{Foreign affiliates alone are responsible for one-third of world trade and 10\% of world GDP, according to the World Investment Report (UNCTAD (1999, 2007)).} 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.\footnote{See Arkolakis et al. (forthcoming), 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".} 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 framework, 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 multinational firms.\footnote{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.} This paper provides the first general equilibrium framework suitable for examining such phenomenon and evaluating corporate tax policies that concerns multinational production.

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 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 maintain tractability. The model yields a system of equations for the equilibrium outcomes, which 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 and Germany would choose lower tax rates than Ireland in the tax competition, i.e., the non-cooperative Nash equilibrium. As a result, the U.S. and Germany gain while Ireland loses. I also find that less trade and multinational activities take place in the Nash equilibrium, implying that countries would become less integrated in the tax competition. 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 better off if corporate taxation is eliminated everywhere. However, the effect of zero taxes on trade and multinational production varies across countries. Following the convention in the MP literature, I also calculate welfare gains from MP, trade, and openness. The result I obtain 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. In other words, 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. (forthcoming) (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, \textit{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. Briefly speaking, 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 non-cooperative Nash equilibrium tax rates, which is known as a tax competition. I find that in the Nash equilibrium, the United States and Germany undercut Ireland. A careful examination on the parameters shows that difference in the size of labor force, i.e., country size, is the main force driving this result. The small country has less incentive to choose a lower tax rate because the increase in equilibrium wage rate caused by MP inflows would crowd out domestic firms and result in profit losses.

Regarding changes in welfare, both the U.S. and Germany would experience welfare gains when moving from the calibrated model to the Nash equilibrium, whereas Ireland would lose as a result of the tax competition. I then continue with a counterfactual exercise in which I eliminate corporate income taxes everywhere. All three countries would be better off in this scenario, compared to the calibrated model. Corporate taxes are distortionary, and the first best is zero taxes everywhere. 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, ARRY 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 is silent about 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. It goes without saying that adding fixed MP costs to the model makes it more complex to solve. To overcome this problem, I follow Tintelnot (2017), who emphasizes the role of fixed MP costs in multinational production, by splitting the firms’ problem into two stages. In the first stage, the distribution of fixed MP costs determines the optimal set of locations for a firm, 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). 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 presents sensitivity analysis. Section 7 concludes.

\footnote{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>
<thead>
<tr>
<th>No.</th>
<th>Affiliates</th>
<th>Net Income</th>
<th>Value Added</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>United Kingdom</td>
<td>Netherlands</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>2</td>
<td>Canada</td>
<td>Luxembourg</td>
<td>Canada</td>
</tr>
<tr>
<td>3</td>
<td>Netherlands</td>
<td>Ireland</td>
<td>Germany</td>
</tr>
<tr>
<td>4</td>
<td>Germany</td>
<td>Bermuda</td>
<td>Ireland</td>
</tr>
<tr>
<td>5</td>
<td>China</td>
<td>Canada</td>
<td>France</td>
</tr>
<tr>
<td>6</td>
<td>France</td>
<td>Switzerland</td>
<td>China</td>
</tr>
<tr>
<td>7</td>
<td>Australia</td>
<td>United Kingdom</td>
<td>Australia</td>
</tr>
<tr>
<td>8</td>
<td>Mexico</td>
<td>UK Is., Caribbean</td>
<td>Switzerland</td>
</tr>
<tr>
<td>9</td>
<td>Luxembourg</td>
<td>Singapore</td>
<td>Japan</td>
</tr>
<tr>
<td>10</td>
<td>Ireland</td>
<td>Mexico</td>
<td>Brazil</td>
</tr>
</tbody>
</table>

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% 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 contribute

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

⁶These 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.

to production. In fact, Ireland and Switzerland are among the top ten locations ranked by 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.
2.2 Tax Cuts and Investment Inflows

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 multinational production adjusts in the period of worldwide tax cut, 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. 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 compiled by Flaaen (2017), 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 where the largest tax cuts occurred 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 to including controls such as changes in GDP and changes in tariffs.

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7These 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.

8See Appendix B.1. for the complete regression results.
Figure 2: Changes in Statutory Corporate Tax Rates and Inward MP Shares (between 1996-2001 and 2006-2011)


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 1 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. 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. 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 1% increase in the after-tax return to capital results in 3% 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-making 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 $\omega$:

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

(1)

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

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

(2)

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

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

(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 potentially produces a single good under monopolistic competition.\footnote{Note that because of the fixed marketing costs that firms face, which will be described below, the measure $M_i$ of firms are not all active in the equilibrium. Some firms are not productive enough to overcome the fixed cost hurdle.}

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 $d$ (i.e. trade), build a production plant in country $d$ and sell the good locally (i.e. horizontal FDI), or build a plant in country $n \neq i, d$ and export the good from country $n$ to country $d$ (i.e. export-platform FDI).

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 $\tau_{dn}$, 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. Under this assumption, a firm from country $i$ will always have a plant at home. However, the firm may become inactive due to the fixed marketing costs. 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 $t_n$.\footnote{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} Tax revenue is rebated to consumers in country.
n through a lump-sum transfer, \( R_n \).

In the spirit of 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 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. Otherwise, the firm becomes inactive in the destination market.

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

### 3.2.1 Production Decision After Plant Location Set is Chosen

Let \( \Delta \) be the set that contains all possible sets of production locations, and denote by \( \delta^* \in \Delta \) the set of locations that firm \( \omega \) from country \( i \) has chosen for production. Assume that \( \delta^* \) 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

\[
c_{dki}(\omega) = \frac{\gamma_{ki}T_{dk}W_k}{z_k}. \tag{4}
\]

For every market \( d \), the firm chooses a production location from set \( \delta^* \) 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 \( p_{dki}(\omega) = \bar{m} c_{dki}(\omega) \), where \( \bar{m} \equiv \frac{\sigma}{\sigma-1} \) 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

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they are not tax-deductible.
after-tax operating profits, which is given by:

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

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

Suppose that country $$n$$ is the location that firm $$\omega$$ 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 $$\tilde{\Pi}_{dni}(\omega) \geq w_d F_d$$, i.e., $$\frac{c_{dni}(\omega)}{(1-t_n)^{\sigma-1}} \leq \tau_d$$, where

$$\tau_d \equiv \left( \frac{X_d}{\sigma w_d F_d} \right)^{\frac{1}{\sigma-1}} \frac{P_d}{m}. \quad (6)$$

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

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

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

with support $$z_k \geq (\tilde{T}_i^\delta)^{1/\theta} \forall k \in \delta$$, where $$\tilde{T}_i^\delta \equiv \left( \sum_{k=1}^{K} T_{ki}^{1-\rho} \right)^{1-\rho}, \rho \in [0, 1)$$, 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 $$\theta$$ governs the dispersion.
of the productivity draws and the parameter \( \rho \) 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 \( 1 - \sum_{k=1}^{K} (T_{ki} \gamma_k^{-\theta}) \). To ensure that there are firms from country \( i \) that will decide not to serve market \( d \), I assume that the cutoff of the tax-adjusted unit cost, \( \bar{c}_d \), is low enough. Formally, as in ARRY, I assume that

\[
\bar{c}_d < \frac{\gamma_{ki} \tau_{dk} w_k}{(1 - t_k)^{1-\rho}} \left( \bar{T}_i^\theta \right)^{-1/\theta} \forall i, k, d, \text{ and } \delta.
\]

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

\[
\Pr \left( \arg \min_k \frac{c_{dk}(\omega)}{(1 - t_k)^{1-\rho}} = n \cap \min_k \frac{c_{dk}(\omega)}{(1 - t_k)^{1-\rho}} = c \Bigg| \delta \right) = \begin{cases} \psi_{dni}^\delta \psi_{di}^\delta \theta c^{\theta-1}, & \text{if } n \in \delta \\ 0, & \text{otherwise} \end{cases}
\]

where

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

and

\[
\psi_{dni}^\delta \equiv \left( \frac{T_{ni} \left( \frac{\gamma_{ni} \tau_{dn} w_n}{(1 - t_n)^{1-\rho}} \right)^{-\theta}}{\psi_{di}^\delta} \right)^{\frac{1}{1-\rho}}.
\]

while the probability that firm \( \omega \) from country \( i \) will serve market \( d \) from country \( n \) is

\[
\Pr \left( \arg \min_k \frac{c_{dk}(\omega)}{(1 - t_k)^{1-\rho}} = n \cap \min_k \frac{c_{dk}(\omega)}{(1 - t_k)^{1-\rho}} \leq \bar{c}_d \Bigg| \delta \right) = \begin{cases} \psi_{dni}^\delta \psi_{di}^\delta (\bar{c}_d)^{\theta}, & \text{if } n \in \delta \\ 0, & \text{otherwise} \end{cases}
\]
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 $\delta$ such that $i \in \delta$, the probability that a firm from country $i$ will produce in country $n \in \delta$ 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 $\delta \in \Delta$, the expected after-tax operating profits for firm $\omega$ 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 $d$: 

18
\[ E \left[ \Pi_{di} \mid \delta \right] = \sum_{n=1}^{K} E \left[ \tilde{\Pi}_{dni}(\omega) \right] \cdot \Pr \left( \arg \min_{k \in \delta} \frac{c_{dki}(\omega)}{(1 - t_k)^{1-\sigma}} = n \cap \min_{k \in \delta} \frac{c_{dki}(\omega)}{(1 - t_k)^{1-\sigma}} \leq \tau_d \mid \delta \right) \]

\[ = \sum_{n=1}^{K} \int_{0}^{\tau_d} (1 - t_n) \frac{1}{\sigma} \left( mc(1 - t_n)^{1-\sigma} \right)^{-1-\sigma} \frac{\psi_{dni}^{\delta}}{\Psi_{dni}^{\delta}} \psi_{dni}^{\delta} \theta c^{\theta-1} dc \]

\[ = \frac{\kappa}{\sigma} \frac{\Psi_{dni}^{\delta}}{\psi_{dni}^{\delta}} \left( \frac{1}{\sigma w_d F_d} \right)^{\frac{\sigma - \sigma + 1}{\sigma - 1}} P_d^\theta X_d^{\theta - 1} \]

(10)

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

\[ E_c \left[ \Pi_i(\omega) \mid \delta \right] = \sum_{d} \left\{ \max \left( E \left[ \Pi_{di} \mid \delta \right] - w_d F_d, 0 \right) \right\} - \sum_{k \in \delta} w_k \varepsilon_{ki}(\omega). \]  

(11)

Notice that the first term is the same for all firms from country \( i \). Since firms do not differ in productivity levels \textit{ex ante}, they form the same expectations with respect to the profits they would earn after paying the fixed MP costs associated with set \( \delta \). 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 \( \Psi_{dni}^{\delta} \) increases with the number of locations, but on the other hand, an additional location entails additional fixed MP costs.

For firm \( \omega \), the set of production locations that maximizes its expected net profits is a function of the vector of fixed MP cost draws \( \varepsilon_i(\omega) = \{ \varepsilon_{i1}(\omega), \ldots, \varepsilon_{Ni}(\omega) \} \). Formally, in the first stage, the firm solves the following maximization problem:

\[ \delta^*(\varepsilon_i(\omega)) = \arg \max_{\delta \in \Delta} E_c \left[ \Pi_i(\omega) \mid \delta \right]. \]  

(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 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, $\varepsilon_i(\omega)$, 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 $\delta$ is then the fraction of the total measure of firms in $i$ for whom set $\delta$ maximizes their expected net profits:

$$M^\delta_i = M_i \int_{\varepsilon} \mathbb{1} [\varepsilon^*(\varepsilon) = \delta] \, dH_i(\varepsilon),$$

and the measure of firms from country $i$ serving market $d$ from country $n$, $M^d_{ini}$, is the
Choose location set \( \delta^* \) conditional on fixed MP costs and country-specific factors

Observe \( z^\delta \), then choose the country with \( \min c_{d_k} \frac{1}{(1 - t_k)^{\frac{1}{\bar{m} - 1}}} \) to serve \( d \)

Serve \( d \) iff \( \frac{c_{dni}}{(1 - t_n)^{\frac{1}{\bar{m} - 1}}} \leq \tau_d \)

**Figure 3: The Firm’s Problem**

measure of firms from \( i \) choosing location set \( \delta \) multiplied by the probability that these firms will serve market \( d \) from location \( n \), summing across all possible location sets:

\[
M_{dni} = \sum_{\delta} M^\delta_i \psi_{dni} \Psi_{di}(\tau_d)^\theta = \left( \frac{X_d}{\sigma w_d F_d} \right)^{\frac{\theta}{\bar{m} - 1}} \frac{P^\theta_d}{m^\theta} \sum_{\delta} M^\delta_i \psi_{dni} \Psi_{di}^\delta. \tag{14}
\]

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):

\[
X_{dni} = \int_0^{c_d} \sum_{\delta} M_i^\delta \psi_{dni}^\delta \Psi_{di}^\delta \theta c^{\theta - 1} (\bar{mc}(1 - t_n)^{\frac{1}{\sigma - \tau}})^{1 - \sigma} P_d^{\sigma - 1} X_d \; dc \\
= \frac{\kappa}{1 - t_n} \left( \frac{1}{\sigma w_d F_d} \right)^{\frac{\theta - \sigma + 1}{\sigma - 1}} P_d^\theta X_d^{\sigma - 1} \sum_{\delta} M_i^\delta \psi_{dni}^\delta \Psi_{di}^\delta, \tag{15}
\]

Combining equations (14) and (15) yields

\[
M_{dni} = (1 - t_n) \frac{\theta - \sigma + 1}{\sigma \theta} X_{dni}. \tag{16}
\]

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

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

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 \( i \):

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

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 \( M_i \), \( \psi_{dni} \), and \( \Psi_{di} \).

Net profits earned by firms from country \( i \), \( \Pi_i \), are the total after-tax profits from sales
\[ X_{dni}, \text{ net of total fixed marketing costs and total fixed MP costs:} \]
\[
\Pi_i = \sum_d \sum_n \left[ (1 - t_n) \frac{1}{\sigma} X_{dni} - w_d F_d M_{dni} \right] - \sum_{\delta \in \Delta} M_i^\delta \int_{\epsilon} \mathbb{1} [\delta^*(\epsilon) = \delta] \sum_{k \in \delta} w_k \varepsilon_{ki} \, dH_i(\epsilon). \tag{19} \]

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 \( i \):
\[
w_i L_i = (1 - \frac{1}{\sigma}) \sum_d \sum_j X_{dij} + w_i F_i \sum_n \sum_j M_{nj} + \sum_{j \in \delta} \sum_{\delta \in \Delta} M_j^\delta \int_{\epsilon} \mathbb{1} [\delta^*(\epsilon) = \delta] w_i \varepsilon_{ij} \, dH_j(\epsilon). \tag{21} \]

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 \( \{\sigma, \theta, \rho, \tau_{dni}, \gamma_{ni}, T_{ni}, t_i, F_i, H_i(\epsilon), M_i, L_i\} \), an equilibrium of the model is a set of wages \( w_i \), price indices \( P_i \), incomes \( X_i \), quantity demanded \( q_i(\omega) \), destination-specific entry cutoffs \( \overline{c}_i \), and location choices \( \delta^* \) such that

(i) \( q_i(\omega) \) satisfies equation (2),
(ii) $\delta^*$ is the solution to equation (12),

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

(iv) $\tau_i$ satisfies equation (6),

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

(vi) $X_i$ 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. For consistency with the time period of the trade and MP data, tax rates are set to be the average statutory corporate tax rates in 1996-2001, a period before the worldwide tax cuts took place. The targeted
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 $T_{ni} = T_{ni}^{1/2} T_{ii}^{1/2}$, 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 $\theta$ and the correlation parameter $\rho$ are calibrated to ARRY’s estimates of the trade elasticity. Specifically, ARRY show that the gravity equation implied by their model can be expressed as

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

(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 $\alpha_{ni}$ and $\eta_{di}$ 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 for the trade elasticity $-\frac{\theta}{1 - \rho}$. Due to the similarity in the model structure, the gravity equation resulting from my model (equation (18)) yields the same estimating equation as in ARRY.\footnote{Taking the log of equation (18) and rearranging terms would give rise to equation (23), where $\alpha_{ni}$ is a location-origin fixed effect given by $\alpha_{ni} = \ln \left( \left[ T_{ni}(\gamma_{ni}w_{ni})^{-\theta} (1 - t_n)^{-\frac{\theta - \sigma + 1}{\sigma}} \right]^{1/\rho} \right)$, and $\eta_{di}$ is a destination-origin fixed effect given by $\eta_{di} = \ln \left( \frac{\sum_{d} \sum_{i} \sum_{\delta} M_{i}^{\delta} \left( \psi_{di}^{\delta} \right) \bar{\tau}_{\delta} \bar{\tau}_{\delta} \Psi_{di}^{\delta} / (1 - t_i) }{ \sum_{j} \sum_{i} \sum_{\delta} M_{j}^{\delta} \left( \psi_{di}^{\delta} \right) \bar{\tau}_{\delta} \bar{\tau}_{\delta} \Psi_{dj}^{\delta} / (1 - t_j) } \right)$.} Hence, I calibrate $-\frac{\theta}{1 - \rho}$ to 10. To disentangle $\theta$ and $\rho$, ARRY estimate an unrestricted gravity equation by regressing the model-generated trade shares on the calibrated trade costs as well as importing and exporting fixed effects. They show that for $\theta = 4.5$ and $\rho = 0.55$ (such that $\frac{\theta}{1 - \rho} = 10$), the model-predicted unrestricted trade elasticity is 5.7 (s.e. 0.15), which is just slightly above the targeted 5 in the data. The model I calibrate only involves three
countries, resulting in nine observations for the unrestricted gravity regression. Nonetheless, with the ARRY estimates for $\theta$ and $\rho$, I obtain an unrestricted trade elasticity of 5.0 (s.e. 0.15), suggesting that $\theta = 4.5$ and $\rho = 0.55$ are reasonable values for the calibration.\(^{14}\) To satisfy the technical restriction $\theta > \sigma - 1$, I choose $\sigma = 4$, which implies a mark-up of 33%.

### 4.2 Parameters Determined in the Equilibrium

The rest of the parameters to be determined include the fixed marketing costs $F_i$, iceberg trade and MP costs $\tau_{dn}$ and $\gamma_{ni}$, and parameters for the distribution of the fixed MP costs, $H_i(\varepsilon)$. Following the convention in the gravity literature, I parameterize the bilateral trade and MP costs using the following functional form:

$$
\ln\tau_{dn} = \beta^\tau + \beta_{\text{dist}}^\tau (\ln \text{dist}_{dn}) + \beta_{\text{lang}}^\tau (\text{lang}_{dn}) \quad \text{for } d \neq n
$$

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

where the variable $\text{dist}$ measures the distance between the most populated cities in the two countries, and $\text{lang}$ is a common language indicator, which takes the value one if the two countries share a common official language. Data on distances and languages are obtained from the CEPII Gravity Database.

There are no fixed costs associated with domestic production. For cross-border production, I assume that the distribution of the fixed MP costs, $H_i(\varepsilon)$, is a log-normal distribution with mean $\mu_{ni}^\varepsilon$ and standard deviation $\beta^\varepsilon$, where

$$
\ln\mu_{ni}^\varepsilon = \beta^\mu + \beta_{\text{dist}}^\mu (\ln \text{dist}_{ni}) + \beta_{\text{lang}}^\mu (\text{lang}_{ni}) \quad \text{for } n \neq i. \quad (24)
$$

The parameterization produces a new set of parameters to be calibrated: $\{F_i, \{\beta^\tau\}, \{\beta^\gamma\}\}$.

\(^{14}\)In Section 6, I perform a sensitivity analysis to examine how different choices of $\rho$ and $\theta$ would affect the model outcomes.
\{\beta^\mu, \beta^\varepsilon\}. In equilibrium, these parameters are jointly identified by a set of moments, which I describe now.

Fixed marketing cost \(F_i\) is crucial in determining the probability of becoming a domestic firm, which is neither an exporter nor a multinational firm. This can be seen by combining equations (9) and (13) and deriving the probability of becoming a domestic firm:

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

Therefore, I calibrate \(F_i\) such that the model-generated probabilities match the share of non-exporters in the data: 0.24 in Germany, 0.47 in Ireland, and 0.82 in the United States.\(^{15}\)

The vector of trade and MP parameters \(\beta = \{\beta^\tau, \beta^\gamma, \beta^\mu, \beta^\varepsilon\}\) determines trade and MP shares as well as the measure of foreign affiliates in each country. In the model, trade shares are defined as the shares of income that consumers in country \(d\) spend on goods produced in country \(n\):

\[
s^R_{dn} = \sum_i X_{dni} X_d;
\] (26)

while MP shares are the shares of output produced by firms from country \(i\) in country \(n\):

\[
s^M_{ni} = \sum_d X_{dni} Y_n;
\] (27)

where \(Y_n \equiv \sum_d \sum_i X_{dni}\) is the total output produced in country \(n\). For their 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 the 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

Table 2: Summary of Calibrated Parameters

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

data on the number of foreign affiliates in each country, 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.\(^{16}\) Intuitively, this ratio is informative as it translates the dispersion in the fixed cost draws into the relative number of foreign 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 \{$F_i$, $\{\beta^\tau\}$, $\{\beta^\gamma\}$, $\{\beta^\mu\}$, $\beta^\varepsilon$\} while solving for the equilibrium outcomes \{$w_i$, $P_i$, $X_i$\}. I develop a three-loop iterative procedure to achieve this goal.

**Inner Loop** Given a set of parameters \{$F_i$, $\{\beta^\tau\}$, $\{\beta^\gamma\}$, $\{\beta^\mu\}$, $\beta^\varepsilon$\} and guesses for wages,
prices and income \( \{w_i, P_i, X_i\} \), the inner loop solves for the equilibrium price indices \( P_i \). In particular, I compute \( \psi^\delta_{dnii}, \Psi^\delta_{di}, \) and \( M^\delta_i \) for all \( d, n, i, \) and \( \delta \), which I then 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 the guesses of \( \{F_i, \{\beta^\tau\}, \{\beta^\gamma\}, \{\beta^\mu\}, \beta^\varepsilon\} \) such that (1) the probabilities of becoming a domestic firm match the data, (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 shares of domestic firms are larger than their data counterparts. I also ensure that with the calibrated \( F_i \), the market-entry cutoff \( \tau_i \) is low enough so that some firms would choose not to serve market \( i \). The parameter \( \beta^\varepsilon \) governs the dispersion of the fixed MP cost draws: a larger \( \beta^\varepsilon \) implies more dispersion. Loosely speaking, I increase the value of \( \beta^\varepsilon \) 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 Tax Competition

As a first exercise, I compute the statutory corporate tax rates for Germany, Ireland, and the United States, under the non-cooperative Nash equilibrium. The outcome constitutes an equilibrium of tax competition, or tax war. 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.

5.1.1 Unilateral Optimal Tax Rates

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.\(^\text{17}\) As tax rate 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 multinational production, governments are able to extract some of the profits of foreign firms. On the one hand, governments would pursue a high tax rate in order 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 and profits 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

\(^\text{17}\)The hump for real tax revenue occurs at very high tax rates (around 90%).
Figure 4: Optimal Corporate Tax Rate in Ireland

*Notes*: This figure depicts how the equilibrium welfare in Ireland (the y-axis) varies with corporate income tax rates in Ireland (the x-axis), holding tax rates in Germany and the United States fixed at the baseline level. The blue solid line corresponds to the Baseline model, and the red dashed line corresponds to autarky, where both trade and multinational production are prohibited. Under each scenario, welfare is normalized to 1 when corporate income tax rate is 0%.

in autarky, a situation where both trade and multinational production are prohibited. Keep in mind that at zero corporate tax rate, welfare in Ireland is 20% lower in autarky than in the Baseline model. However, for presentation purpose, I also normalize welfare to 1 when tax rate is 0% in autarky. As shown in Figure 4, welfare is monotonically decreasing as tax rate increases in autarky, giving rise to the optimal tax rate of 0% in Ireland. Without the possibility of cross-border production, firms can only produce at home. A positive tax rate is detrimental as it greatly distorts firms’ entry. Recall that the three components of welfare are real wages, real profits, and real tax revenue. 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
Figure 5: The Effect of Tax Rate 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 (the x-axes), holding tax rates in Germany and the United States fixed at the baseline level. The blue solid line corresponds to the Baseline model, and the red dashed line corresponds to autarky, where both trade and multinational production are prohibited. 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.

Tax revenue is lower and increases at a slower rate as tax rate increases. The three findings are illustrated graphically in Figure 5. The sharp decrease in profits and slow increase in tax revenue determine the zero optimal tax rate in autarky.

The optimal tax rates for Germany and the United States are also positive in the Baseline model and zero in autarky. Figures for these two countries are included in Appendices B.2. and B.3. Note that the optimal corporate income rate in the United States is sufficiently lower than the ones in the other two countries. As shown in Figure 7 in Appendix B.3., unlike Germany and Ireland, the effect of tax rate on real wages, real profits, and real tax income in the U.S. are very similar in the Baseline model and in autarky. This is driven by the fact that the U.S. is mainly the home, rather than the host, of multinational activities. The majority firms in the U.S. are domestic firms. For this reason, the U.S. government would need to maintain a low tax rate so as to minimize the distortion to domestic firms’ entry.
5.1.2 Nash Corporate Income Tax Rates

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

Step 1: Fix the 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 their current optimal tax rate.

Step 2: Compute the optimal tax rate for the United States given the optimal tax rates of Ireland and Germany, which was solved in Step 1. 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 the Baseline tax rates). Using the baseline calibration, 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. The Nash tax rates for Germany, Ireland, and the United States are 14%, 26%, and 4%, respectively. Under tax competition, the United States dramatically undercuts the other two countries.\(^\text{18}\) When moving from Baseline to Nash equilibrium, the U.S. and Germany experience roughly 1% increase in welfare, whereas Ireland encounters a welfare loss of 0.4%. 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

\(^{18}\text{See Section 5.1.3 for an analysis on the forces that give rise to this result.}\)
Table 3: Nash Corporate Tax Rates under Baseline Model

<table>
<thead>
<tr>
<th></th>
<th>Baseline tax rates (%)</th>
<th>Nash tax rates (%)</th>
<th>ΔWelfare (%)</th>
<th>ΔInward MP Share (p.p)</th>
<th>ΔImport Share (p.p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>50</td>
<td>14</td>
<td>0.78</td>
<td>-1.53</td>
<td>-1.11</td>
</tr>
<tr>
<td>Ireland</td>
<td>34</td>
<td>26</td>
<td>-0.39</td>
<td>-2.42</td>
<td>-4.00</td>
</tr>
<tr>
<td>United States</td>
<td>39</td>
<td>4</td>
<td>0.90</td>
<td>-0.88</td>
<td>-0.26</td>
</tr>
</tbody>
</table>

Notes: Entries under Baseline and Nash are statutory corporate tax rates (in percent) in the Baseline and Nash equilibria, respectively; entries under ΔWelfare are counterfactual welfare changes (in percent) when moving from the Baseline tax rates to the Nash tax rates. Entries under ΔInward 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 ΔImport Share are the changes in import share (in percentage point), defined as the share of imports in total absorption.

in total output produced in the country. The import share is defined as the share of imports in total absorption. Conditional on a firm choosing to serve a foreign market, the lower tax rates make MP relatively more attractive, which leads to a decrease in import shares in all countries. Inward MP shares also decrease everywhere in the Nash equilibrium. With lower tax rates everywhere in the Nash equilibrium, more firms are able to overcome the entry hurdle and become active. The extremely low tax rate in the U.S. drives U.S. firms to relocate their foreign affiliates back home, which results in a decrease in the inward MP shares in Germany and Ireland, by 1.53 percentage points and 2.42 percentage points, respectively. The U.S. also experience a slight decrease in its inward MP share, by 0.88 percentage points. This is largely due to domestic firm entry and relocation. Taken as a whole, countries are less integrated in the Nash equilibrium than in the Baseline model.
5.1.3 Forces Driving the Result

We see that in the Nash equilibrium, U.S. significantly undercuts the other two countries. What are the forces that drive this result? In this section I conduct an investigation on the parameters in the model.

I begin with Case 1, a symmetric case in which countries A, B, and C are identical. All parameters are calibrated to U.S. values or U.S.-Germany-pair values. I compute the Nash tax rates under this scenario. Then, I continue with a few exercises in which I change one parameter at a time and compute a new set of Nash tax rates. In Case 2, I decrease the iceberg trade cost between countries A and B. In Case 3, I decrease the iceberg MP cost between countries A and B. Lastly, in Case 4, I assume countries A and B are smaller than country C. To do so, I impose that countries A and B have the same size of labor force as in Germany, and country C has the labor force size of the U.S. The results are summarized in Table 4.

In Case 1, all three countries set identical tax rates in the Nash equilibrium, at 11%. When the iceberg trade cost is lower between countries A and B than the ones involving country C, firms from countries A and B would prefer MP over trade when serving country C. Therefore, country C has some power to set a slightly higher tax rate than the other two countries in the equilibrium. The opposite story goes when the iceberg MP cost is lower between countries A and B than the ones involving country C, as shown in row 3. In Case 4, when countries A and B are smaller than country C, we see that country C imposes a much lower corporate tax rate in the Nash equilibrium. The outcome in this scenario is very similar to the Nash tax rates under the Baseline calibration, implying that country size may be the most important factor that drives the result in Section 5.1.2.

Previous work in the tax competition literature has also focused on country size as a determinant of tax rate differences (Bucovetsky (1991), Wilson (1991), Kanbur and Keen (1993)). The main result is that, for both commodity taxation and capital taxation, the
Table 4: Nash Corporate Tax Rates under Different Scenarios

<table>
<thead>
<tr>
<th>Case</th>
<th>Description</th>
<th>Nash tax rates (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Country A</td>
</tr>
<tr>
<td>Case 1</td>
<td>Symmetry</td>
<td>11</td>
</tr>
<tr>
<td>Case 2</td>
<td>$A, B$ low $\tau$</td>
<td>7</td>
</tr>
<tr>
<td>Case 3</td>
<td>$A, B$ low $\gamma$</td>
<td>16</td>
</tr>
<tr>
<td>Case 4</td>
<td>$A, B$ low $L$</td>
<td>18</td>
</tr>
</tbody>
</table>

Notes: Entries under Nash tax rates are the statutory corporate tax rates (in percent) in the Nash equilibrium, for countries $A$, $B$, and $C$, under four different scenarios described in column 2.

small country would undercut the large country. The intuition behind this is that for the small country, the revenue loss from a tax cut is dominated by the revenue gains from the inflows of foreign capitals and investments. The small country faces a more elastic supply of mobile tax base than the large country. Therefore, it sets a lower tax rate in order to attract a larger share of the mobile tax base from the large country. My model, on the contrary, predicts that the large country would undercut the small country in the tax competition. This is because unlike the models in the tax literature where foreign investment only takes the form of capital flows, the multinational activities that this paper considers involve actual production. Production requires labor input, and multinational production affects wages in the general equilibrium. If the small country were to compete with the large country and set a lower tax rate, then the tremendous amount of MP inflows would cause the equilibrium wage in the small country to increase sharply. A direct effect of this wage increase is that less-productive domestic firms in the small country exit the market, and the small country suffer from profit losses. Hence, to prevent domestic firms from crowding out, the small country would not undercut the large country.
5.2 Elimination of Corporate Taxes

In the second counterfactual exercise, I examine the consequences of eliminating corporate income taxes. As shown in column 1 of Table 5, if corporate tax rates are zero everywhere, welfare would increase by 1.65%, 0.06%, and 1.30% in Germany, Ireland, and the United States, respectively. Moving to zero tax rates, the increase in profits and wages dominates the decrease in tax revenue for all countries. This result confirms that corporate taxes are distortionary and that the first best is zero taxes.

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. The opposite happens for import shares.

<table>
<thead>
<tr>
<th></th>
<th>∆Welfare (%)</th>
<th>∆Inward MP Share (p.p)</th>
<th>∆Import Share (p.p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>1.65</td>
<td>1.91</td>
<td>-0.38</td>
</tr>
<tr>
<td>Ireland</td>
<td>0.06</td>
<td>2.71</td>
<td>-1.53</td>
</tr>
<tr>
<td>United States</td>
<td>1.30</td>
<td>-0.02</td>
<td>0.10</td>
</tr>
</tbody>
</table>

*Notes: Entries under ∆Welfare are the welfare changes (in percent) when countries move from the Baseline tax rates to zero tax rates. Entries under ∆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 ∆Import Share are the changes in import share (in percentage point), defined as the share of imports in total absorption.*
5.3 Welfare gains from MP, Trade, and Openness

I conclude the quantitative analysis with a series of counterfactual exercises to highlight the importance of multinational production, trade, and openness to welfare analysis. Table 6 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.

<table>
<thead>
<tr>
<th></th>
<th>MP</th>
<th>Trade</th>
<th>Openness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>1.0184</td>
<td>1.0115</td>
<td>1.0350</td>
</tr>
<tr>
<td>Ireland</td>
<td>1.0656</td>
<td>1.0973</td>
<td>1.1815</td>
</tr>
<tr>
<td>United States</td>
<td>1.0053</td>
<td>1.0031</td>
<td>1.0099</td>
</tr>
</tbody>
</table>

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.
6 Sensitivity Analysis

I present a sensitivity analysis to evaluate the performance of the calibrated model. In particular, I show how Nash tax rates change had I calibrated $\rho$ and $\theta$ differently. Recall that $\rho$ and $\theta$ are parameters of the multivariate Pareto distribution, which governs the correlation and dispersion of the productivity draws, respectively.

**Correlation parameter** The parameter $\rho$ takes values in $[0, 1)$. If $\rho \to 1$, the productivity draws are perfectly correlated, and if $\rho = 0$, the productivities are independently drawn from the Pareto distribution $1 - \sum_{k=1}^{K} (T_k z_k - \theta_k)$. In the Baseline model, I calibrate $\rho$ to be 0.55. The resulting Nash tax rates are 14%, 26%, and 4% for Germany, Ireland, and the United States, respectively. In this exercise, I choose different values of $\rho$, namely 0 and 0.99, and compute Nash equilibrium tax rates for the three countries. The results are shown in Panel A of Table 7.

When the plant-specific productivities are nearly perfectly correlated, i.e. $\rho = 0.99$, the Nash equilibrium tax rates are slightly lower than the Baseline Nash rates across countries. And when the draws are independently drawn from the distribution, i.e., $\rho = 0$, the resulting Nash tax rates are higher than the Baseline. Intuitively, if all the plants are very similar in terms of productivities, then firms are footloose as to where to locate their affiliates. Thus, governments are likely to set lower tax rates in order to attract firms. On the other hand, if the plants are very different in their productivity levels, then firms’ location choices are less elastic with respect to tax rates. Under such circumstances, governments have the power to target higher tax rates.

**Dispersion parameter** The parameter $\theta$ governs the dispersion of the productivity draws. A larger $\theta$ implies less dispersion. I set $\theta$ to be 4.5 in the Baseline model. In Panel B of Table 7, I present the Nash tax rates under two other scenarios: $\theta = 5$ and $\theta = 4$. It is clear
Table 7: Sensitivity Analysis

<table>
<thead>
<tr>
<th>Nash tax rates (%)</th>
<th>Germany</th>
<th>Ireland</th>
<th>U.S.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Panel A</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\rho = 0.55$ (Baseline)</td>
<td>14</td>
<td>26</td>
<td>4</td>
</tr>
<tr>
<td>$\rho = 0.99$</td>
<td>13</td>
<td>24</td>
<td>4</td>
</tr>
<tr>
<td>$\rho = 0$</td>
<td>18</td>
<td>27</td>
<td>6</td>
</tr>
<tr>
<td><strong>Panel B</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\theta = 4.5$ (Baseline)</td>
<td>14</td>
<td>26</td>
<td>4</td>
</tr>
<tr>
<td>$\theta = 5$</td>
<td>9</td>
<td>21</td>
<td>2</td>
</tr>
<tr>
<td>$\theta = 4$</td>
<td>22</td>
<td>33</td>
<td>7</td>
</tr>
</tbody>
</table>

*Notes: Entries under Nash tax rates are the statutory corporate tax rates (in percent) in the Nash equilibrium with different values of $\rho$ (Panel A) and $\theta$ (Panel B).*

from the table that Nash tax rates decrease as the value of $\theta$ increases. This is because when $\theta$ is low, there is more dispersion in the productivity draws. As firms’ response to tax rates are more inelastic, governments are able to choose higher tax rates.

Although Nash equilibrium tax rates change as the values of $\rho$ and $\theta$ change, the magnitude is not large. More importantly, qualitative result of the model is unaffected.

7 Conclusion

The determinants and consequences of multinational production have been widely studied. In this paper, I focus on one particular determinant of multinational production, namely 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 of counterfactual exercises. Computing the non-cooperative Nash equilibrium tax rates using an iterative algorithm, I find that in the tax competition, large countries would undercut small countries and experience welfare gains. The main driving force of this result is the difference in country size. In another exercise where I eliminate corporate income taxes everywhere, I find that all countries are better off if they set zero tax rates simultaneously. Lastly, I quantify gains from multinational production, trade, and openness. Consistent with the literature, the model predicts that small countries benefit more from an open regime than large countries.

This paper develops the first general equilibrium framework that is designed to study the relationship between corporate income taxation, international trade, and multinational production. It can be extended to investigate other interesting topics along these lines. For example, instead of rebating tax revenue to consumers via a lump-sum transfer, government could use the tax revenue to produce public goods. The extended model can be useful to study government’s objectives. With some modification, this model can also be applied to examine the international investments driven by profit-shifting motives. Future research will focus on these directions.
References


Appendix A: Proofs and Results

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

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

$$
\Pr \left( \frac{C_{dli}}{(1 - t_1)^{\frac{1}{\sigma - 1}}} \geq c_{dli}, \ldots, \frac{C_{dni}}{(1 - t_n)^{\frac{1}{\sigma - 1}}} \geq c_{dni}, \ldots, \frac{C_{dKi}}{(1 - t_K)^{\frac{1}{\sigma - 1}}} \geq c_{dKi} \bigg| \delta \right) = \Pr \left( Z_1 \leq \frac{\gamma_{li} \tau_{l1} w_1}{(1 - t_1)^{\frac{1}{\sigma - 1}} c_{dli}}, \ldots, Z_K \leq \frac{\gamma_{Ki} \tau_{dK} w_K}{(1 - t_K)^{\frac{1}{\sigma - 1}} c_{dKi}} \bigg| \delta \right) = 1 - \left[ \sum_{k=1}^{K} \left( T_{ki} \left( \frac{\gamma_{ki} \tau_{dk} w_k}{(1 - t_k)^{\frac{1}{\sigma - 1}} c_{dki}} \right)^{-\theta} \right)^{\frac{1}{1 - \theta}} \right]^{1 - \rho}. \quad (A.1)
$$

Since

$$
\frac{C_{dli}}{(1 - t_1)^{\frac{1}{\sigma - 1}}} \geq c_{dli}, \ldots, \frac{C_{dni}}{(1 - t_n)^{\frac{1}{\sigma - 1}}} \geq c_{dni}, \ldots, \frac{C_{dKi}}{(1 - t_K)^{\frac{1}{\sigma - 1}}} \geq c_{dKi} \bigg| \delta \right) = \frac{\partial \Pr \left( \frac{C_{dli}}{(1 - t_1)^{\frac{1}{\sigma - 1}}} \geq c_{dli}, \ldots, \frac{C_{dni}}{(1 - t_n)^{\frac{1}{\sigma - 1}}} \geq c_{dni}, \ldots, \frac{C_{dKi}}{(1 - t_K)^{\frac{1}{\sigma - 1}}} \geq c_{dKi} \bigg| \delta \right)}{\partial c_{dni}},
$$

from equation (A.1) we have that

$$
\Pr \left( \frac{C_{dli}}{(1 - t_1)^{\frac{1}{\sigma - 1}}} \geq c_{dli}, \ldots, \frac{C_{dni}}{(1 - t_n)^{\frac{1}{\sigma - 1}}} \geq c_{dni}, \ldots, \frac{C_{dKi}}{(1 - t_K)^{\frac{1}{\sigma - 1}}} \geq c_{dKi} \bigg| \delta \right) = \theta \left[ \sum_{k=1}^{K} \left( T_{ki} \left( \frac{\gamma_{ki} \tau_{dk} w_k}{(1 - t_k)^{\frac{1}{\sigma - 1}} c_{dki}} \right)^{-\theta} \right)^{\frac{1}{1 - \theta}} \right]^{\frac{1}{1 - \theta}} c_{dni}^{\frac{\theta - 1}{\theta}}.
$$
If \( c < (\gamma_{ki} \tau_{dk} w_k)(\tilde{T}_i^\delta)^{-1/\theta} \forall k \), then the probability that a firm from country \( i \) will serve market \( d \) from country \( n \in \delta \) at tax-adjusted cost \( c \) is

\[
\Pr \left( \arg \min_{k \in \delta} \frac{c_{dki}}{(1 - t_k)^{\frac{1}{\sigma - 1}}} = n \cap \min_{k \in \delta} \frac{c_{dki}}{(1 - t_k)^{\frac{1}{\sigma - 1}}} = c \mid \delta \right)
= \Pr \left( \frac{C_{dii}}{(1 - t_1)^{\frac{1}{\sigma - 1}}} \geq \ldots, \frac{C_{dni}}{(1 - t_n)^{\frac{1}{\sigma - 1}}} = \ldots, \frac{C_{dki}}{(1 - t_k)^{\frac{1}{\sigma - 1}}} \geq c \mid \delta \right)
= \theta \left[ \sum_{k=1}^{K} \left( T_{ki} \left( \frac{\gamma_{ki} \tau_{dk} w_k}{(1 - t_k)^{\frac{1}{\sigma - 1}}} \right)^{-\theta^{1-\rho}} \right) \right]^{-\rho} \prod_{n \in \delta} \left( T_{ni} \left( \frac{\gamma_{ni} \tau_{dn} w_n}{(1 - t_n)^{\frac{1}{\sigma - 1}}} \right)^{-\theta^{1-\rho}} \right) \psi_{dni}^\delta \psi_{dni}^\delta \theta^\theta - 1.
\]

(A.2)

Given the assumption that \( T_d < \frac{\gamma_{ni} \tau_{dn} w_n}{(1 - t_k)^{\frac{1}{\sigma - 1}}} (\tilde{T}_i^\delta)^{-1/\theta} \forall i, n, d \) and \( \delta \), 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 \( T_d \):

\[
\Pr \left( \arg \min_{k \in \delta} \frac{c_{dki}}{(1 - t_k)^{\frac{1}{\sigma - 1}}} = n \cap \min_{k \in \delta} \frac{c_{dki}}{(1 - t_k)^{\frac{1}{\sigma - 1}}} \leq T_d \mid \delta \right) = \psi_{dni}^\delta \psi_{dni}^\delta \theta \int_0^{T_d} c^{\theta - 1} dc
= \psi_{dni}^\delta \psi_{dni}^\delta \theta (T_d^\theta).
\]

A.2. Proof of Lemmas

**Lemma 1 (Intensive margin effect)** For a given location set \( \delta \) such that \( i \in \delta \), the probability that a firm from country \( i \) will produce in country \( n \in \delta \) 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 \( n \in \delta \), we have
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

\[
\left\{ -\sum_{k=1}^{K} \left( \frac{\gamma_{k} t_{d_{k}} w_{k}}{(1 - t_{k})^{\sigma}} \right)^{-\theta} \right\} \frac{1}{\rho} + \rho \left( 1 - t_{n} \right)^{\sigma(1 - \theta)} \left( \frac{T_{n_{i}} \left( \gamma_{n_{i}} t_{d_{n}} w_{n} \right)^{-\theta}}{(1 - t_{n})^{\sigma}} \right)^{\frac{1}{1 - \rho}}
\]

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

\[
\rho \left( \frac{\gamma_{n_{i}} t_{d_{n}} w_{n}}{(1 - t_{n})^{\sigma}} \right)^{-\theta} \frac{1}{\rho} \sum_{k=1}^{K} \left( \frac{\gamma_{k} t_{d_{k}} w_{k}}{(1 - t_{k})^{\sigma}} \right)^{-\theta} \frac{1}{\rho}.
\]

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

\[\text{Lemma 2 (Extensive margin effect)} \text{ The probability that a firm chooses a location set containing country } n \text{ over a location set that does not contain country } n \text{ is a decreasing function of the corporate tax rate of country } n, t_{n}.\]

\[\text{Proof: The probability that a firm chooses a location set containing country } n \text{ over a} \]

48
The term after the "$\geq$" sign is not affected by the tax rate in country $n$ since $n \not\in \delta'$. The term before the "$\geq$" sign, however, decreases with the tax rate in country $n$ since

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

and $\frac{\partial \phi_d}{\partial t_n} < 0$. Hence, the overall probability is a decreasing function of the tax rate imposed by country $n$, $t_n$.  

\[ \blacksquare \]
### Appendix B: Additional Tables and Figures

#### B.1. Table of Regression Results for Figure 2

<table>
<thead>
<tr>
<th>Dependent variable: $\Delta$Inward MP shares</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta$Tax rate</td>
<td>-0.76**</td>
<td>-0.72**</td>
<td>-0.69*</td>
</tr>
<tr>
<td></td>
<td>(0.31)</td>
<td>(0.34)</td>
<td>(0.34)</td>
</tr>
<tr>
<td>$\Delta$GDP</td>
<td>-0.0008</td>
<td>-0.0017</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0013)</td>
<td>(0.0015)</td>
<td></td>
</tr>
<tr>
<td>$\Delta$Tariff</td>
<td></td>
<td></td>
<td>-1.63**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.58)</td>
</tr>
<tr>
<td>No. Obs</td>
<td>23</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.27</td>
<td>0.27</td>
<td>0.30</td>
</tr>
</tbody>
</table>

*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

![Graphs showing the relationship between corporate income tax rates and welfare in Germany and the United States.](image)

**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 lines correspond to the Baseline model, and the red dashed lines correspond to autarky, where both trade and multinational production are prohibited. Under each scenario, welfare is normalized to 1 when the country’s own corporate income tax rate is 0%. 

51
B.3. The Effect of Tax Rate on Real Wages, Profits, and Tax Revenue in Germany and the United States

Figure 7: The Effect of Tax Rate on Real Wages, Profits, and Tax Revenue in Germany and the United States

Notes: This figure depicts how the equilibrium (a) real wages (b) real profits, and (c) real tax revenue 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 lines correspond to the Baseline model, and the red dashed lines correspond to autarky, where both trade and multinational production are prohibited. Baseline values in (a) and (b) are normalized to 1 when tax rate is 0% and baseline real tax revenue is normalized to 1 when tax rate is 1%.