# Multinational Production and Corporate Taxes: A Quantitative Assessment

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May 20, 2019

**Abstract**

I study the welfare implications of corporate taxation in the presence of multinational production (MP) in order to understand the consequences of international tax competition and cooperation. I build a quantifiable multi-country general equilibrium model with trade, MP, and salient features of international corporate tax system. The model delivers structural equations that can be used to estimate the model's key parameters governing the response of firms' production locations to changes in corporate tax rates. Calibrating the model to data on 28 countries, I find that the U.S. corporate tax reform in 2017 would increase the U.S. real income by about 1% but decrease the average real income of other countries by 0.075%. In a non-cooperative tax game, I find that each country has strong incentives to lower its corporate tax rate on domestic firms in order to gain from firm relocation at the expense of other countries, which leads to welfare losses in participation countries. International tax cooperation can increase the real income in each participation country by about 1%.

**Keywords:** *Multinational production; corporate tax; tax competition; tax cooperation*

**JEL classification:** *F23, F42, F12, F13, O19*

*I am grateful to Stephen Yeaple for his continuous guidance and support. I thank Yuan Zi and Lixin Tang for extensive discussions and in-depth comments. I thank the editor and the referees for insightful suggestions that helped improve this paper. All errors are my own. Correspondence: wang.zi@mail.shufe.edu.cn. Please see https://sites.google.com/site/icebergzw/research for the latest version and replication files.

# 1 Introduction

In the era of globalization, corporate income tax is no longer solely a domestic policy since (i) multinational enterprises (MNEs) account for a large fraction of global production and (ii) corporate taxes have been shown to be influential for the spatial allocation of MNEs' activities.[1] International corporate tax competition and cooperation have drawn increasing attention from researchers and policy makers.[2] In the presence of multinational production (MP), what are the welfare and distributional implications of corporate taxes? What would occur if international tax treaties were abandoned? What would be the outcome if countries engaged in tax cooperation? These questions are key for understanding international corporate tax policies. However, there is currently a lack of tractable models that connect theoretical answers to these questions to data, a gap that this paper aims to fill.

In this paper, I quantify the aggregate effects of corporate taxes in the presence of MP and analyze noncooperative and cooperative corporate tax policies. To achieve these, I develop a quantifiable multi-country general equilibrium model that incorporates trade, MP, and salient features of the international corporate tax system. In the model, firms decide their production locations based on each country's corporate tax rates, wages, size, productivity, and trade and MP barriers to other countries. I use bilateral MP sales across 28 countries and their corporate tax rates to estimate the model's key parameters. Using the estimated model, I compute in multi-country general equilibrium the effects of the recent corporate tax reform in the U.S. and the potential tax reform in the U.K. after Brexit. I also compute Nash and cooperative corporate tax rates to shed light on the causes and consequences of international corporate tax competition and cooperation.

My model builds on the quantitative MP model developed by Arkolakis et al. (henceforth ARRY, 2018). In the model, firms can geographically separate their creation of differentiated goods ("innovation") with production, allowing some countries to specialize in innovation and others to specialize in production. As in ARRY (2018), specialization in innovation or production depends on comparative advantage as well as geography. My model extends the ARRY model in two dimensions. First, I allow a country to levy corporate taxes on firms that produce there.[3] In particular, I allow each *host* country, as in practice, to impose

[1] For example, Huizinga and Voget (2009) show that international double taxation has substantial impacts on cross-border M&A. Barrios et al. (2014) show that both host and parent country taxes have negative effects on the location of new foreign subsidiaries.

[2] A recent example is the hot debates on corporate tax competition among OECD countries. According to *Financial Times* on September 13th, 2017, "Eight (OECD) countries reduced their corporate tax rates in 2017, with cuts averaging 2.7 percentage points."

[3] This specification resembles the corporate tax system in which MNEs' income is taxed where the income

different corporate tax rates on firms originated from different *source* countries. Second, I allow firms to shift part of their profits to low tax countries. This extension captures the tax avoidance by MNEs and the differences between statutory and effective corporate tax rates due to profit shifting. With many countries, international corporate taxation, and profit shifting, the model still yields closed-form gravity equations of bilateral trade and MP flows. Based on these structural equations, I estimate model parameters and conduct counterfactual analysis.

I rely on special cases of my model to characterize analytically a country's incentive to manipulate its corporate taxes. The key mechanism in my analysis is the home market effect in innovation. Other things equal, firms tend to create differentiated goods ("innovate") in a country that has low barriers to outward MP but high barriers to inward MP. By imposing higher corporate tax rates on foreign firms[4] than on domestic firms, a country effectively increases its inward MP cost, inducing firm entry and boosting innovation. Since innovation is an increasing-returns-to-scale activity, countries gain from this home market effect in innovation. In the special case with two symmetric countries, I show that the unilaterally optimal tax rate on foreign firms is much higher than the one on domestic firms. In reality, we usually do not observe such huge tax gaps between foreign and domestic firms. However, if we take all subsidies that target on domestic firms into account, the optimal taxes in this paper would indeed be relevant to policy practices in many countries.

The parameters that govern how firms relocate their plants in response to changes in corporate taxes are key for my quantification. The model generates a structural equation that expresses bilateral MP flows as a function of bilateral corporate tax rates, frictions to MP, and source- and host-country-specific factors. Using data on MP sales and corporate taxes in 28 countries, I estimate the impact of bilateral corporate tax rates on bilateral MP sales, which yields an elasticity of MP entry with respect to corporate tax rates of 7.69. This estimate is in line with the elasticity of MP entry with respect to MP costs that has been estimated in ARRY (2018) using alternative strategies.

The model is then calibrated to match data on bilateral trade and MP flows across 28 countries and the profits shifted by the U.S. MNEs documented by Bruner et al. (2018). I use the calibrated model to quantify the impacts of two corporate tax reforms. First, the

is earned. An alternative system is the "residence-based" corporate taxation in which MNEs' income is taxed where the firms are originated. The reason why I focus on the corporate taxes collected by host countries will be discussed in details in Section 2.2.

[4] In this paper, "foreign firms" means "the affiliates of foreign MNEs", whereas "domestic firms" means "firms that are created domestically, regardless where they produce". In other words, both foreign and domestic refer to innovation countries, not production countries.

United States reduced its corporate tax rate by about 13 percentage points in 2017. My quantitative analysis suggests that this tax cut would increase the real income in the U.S. by about 1% but decrease the average real income of other countries by 0.075%. Moreover, the U.S. innovation workers would gain more from this tax cut than the U.S. production workers. Second, I consider the potential corporate tax reform in the United Kingdom after Brexit. Motivated by Brexit, I increase trade and MP costs between the U.K. and the EU countries by 5%. This will reduce the real income in the U.K. by 1.7%. However, if the U.K. reduces its corporate tax rate by 12 percentage points, then its welfare loss from Brexit will decrease to 1.2%. In other words, the U.K. tax cut could compensate about one third of the welfare loss led by Brexit.

I then investigate non-cooperative corporate taxes across countries, starting by considering *optimal* corporate taxes, i.e., the corporate taxes countries would impose if they do not fear any retaliation. Consistent with the analytical results, each country can gain considerably at the expense of other countries by imposing higher corporate tax rates on foreign firms than on domestic firms. The average optimal corporate tax rate for domestic firms is -2.47%, whereas the average optimal corporate tax rate for foreign MNEs is 33.5%. These taxes will lead to the average 1.6% welfare gain in the tax-imposing country and the average -0.05% welfare loss in other countries.

I turn to analyze *Nash* corporate taxes among eight major countries in MP activities.[5] The average Nash corporate tax rates are -1.56% on domestic firms and 38.7% on foreign firms. This distorted tax structure substantially reduces MP and leads to welfare losses: five out of eight countries incur welfare losses relative to the factual equilibrium, whereas all eight countries incur welfare losses relative to the tax-free equilibrium. Interestingly, in the absence of profit shifting, tax competition would lead to much larger welfare losses for participation countries. This is because the effective Nash corporate tax rates on foreign MNEs would be higher if these firms cannot shift their profits to low tax countries.

Finally, I investigate *cooperative* corporate taxes across eight countries involved in tax competition, i.e., the taxes these countries would impose under efficient tax negotiation. The results show that tax cooperation decreases corporate tax rates dramatically in all participation countries, triggering firm entry and benefiting everyone. Tax negotiation starting from factual taxes increases the real income in each participation country by 0.98%. Notably, the factual corporate taxes on foreign firms are much closer to cooperative taxes than to Nash taxes, which highlights the effectiveness of international tax treaties that coordinate

[5] They are Belgium, Canada, Germany, France, Britain, Ireland, the Netherlands, and the U.S. I bundle other countries as the rest of the world.

corporate taxation across borders.

To the best of my knowledge, this is the first quantitative analysis of corporate taxation in a multi-country environment with MP. Theoretical work including but not limited to Zodrow and Mieszkowski (1986), Wilson (1986), Kanbur and Keen (1993), Gordon and Mackie-Mason (1995), Gordon and Hines (2002), Jonannesen (2016), Devereux (2014), and Devereux et al. (2008) analyzes welfare implications of corporate taxes for both tax-imposing countries and other countries. These models illustrate the *qualitative* effects of international tax competition on MP and welfare, but work with a small open economy or two countries. Hence, it is difficult to bring those models to data and assess their *quantitative* importance. In this paper, I incorporate corporate taxation into a multi-country general equilibrium model with trade and MP and quantify its welfare implications.

My model builds on the quantitative MP model developed by ARRY (2018). A nice feature of their model is that they allow export-platform FDI but still obtain analytical gravity equations for aggregate trade and MP flows. However, ARRY (2018), together with other quantitative MP models such as Ramondo and Rodriguez-Clare (2013), Tintelnot (2017), and Irarrazabal et al. (2013), focus on the welfare effects of MP without considering corporate tax policies. I extend ARRY (2018) by incorporating the international corporate tax system summarized by Huizinga and Voget (2009) and the MNEs' profit shifting documented by Bruner et al. (2018).

My work is also inspired by the international commercial policy literature in the spirit of Bagwell and Staiger (1999). In particular, I calculate optimal taxes, Nash taxes, and cooperative taxes just like trade policy researchers calculate optimal tariffs, Nash tariffs, and cooperative tariffs. The quantitative techniques I use here to compute Nash and cooperative taxes draw from the quantitative techniques in Ossa (2014) that are used to study tariff wars and tariff talks. Ossa (2016) also uses similar techniques to analyze subsidy competition among the U.S. states. My work is the first attempt in applying this technique to assess international corporate taxation. Nash taxes and cooperative taxes are both extremes that are useful to understanding international tax conflicts and treaties in reality.

The structural estimation in this paper is related to empirical studies on the effects of corporate taxes on the spatial allocation of MNEs' activities. Barrios et al. (2009) show that host and parent country corporate taxes have a negative impact on the location of new foreign subsidiaries. Huizinga and Voget (2009) apply the gravity model to estimate the impact of international double taxation on bilateral numbers of merger and acquisition. Huizinga, Voget, and Wagner (2014) find that international double taxation of foreign-source bank income reduces banking-sector FDI. My empirical estimates are consistent with their findings and are used as an input for my quantitative analysis.

The remainder of the paper is organized as follows. Section 2 presents the theoretical framework describing the economic environment and the equilibrium given corporate tax rates. Section 3 characterizes the welfare implications of corporate taxes in special cases. In section 4, I structurally estimate the model's key parameters and calibrate the model to data on 28 countries. Section 5 quantifies the aggregate effects of corporate tax reforms in reality. Section 6 investigates the consequences of potential tax wars and tax talks among eight major countries in MP activities. Section 7 concludes.

# 2 A Model of MP and Corporate Taxation

This section presents a theoretical framework that guides my quantitative analysis. The framework builds on the quantitative MP model of ARRY (2018) and extends it to capture salient features of international corporate taxation. As I go through the model, I explain how corporate taxes in the model can be linked to policy tools used by governments in reality. The specification of corporate taxation in the model is in line with an extensive literature of international corporate taxation.[6] I consider corporate tax rates chosen by a government with an objective function developed by Ossa (2014, 2016).

## 2.1 Preferences and Technologies

I consider a world economy comprised of $i = 1, \ldots, N$ countries; one factor of production, labor; and a continuum of goods indexed by $\omega$. Preferences are constant elasticity of substitution (CES) with elasticity of substitution $\sigma > 1$.

Each good $\omega$ is produced by a firm using labor under monopolistic competition. A firm can create good $\omega$ in country $i$ by paying a fixed entry cost $f^e$ in units of country $i$'s labor. Following and Melitz (2003) and ARRY (2018), I regard this creation of firms that sell differentiated goods in monopolistically competitive markets as *innovation*. Post entry, a firm can potentially produce anywhere in the world. This unbundling of firm entry and production allows some countries to specialize in innovation and others to specialize in production. Moreover, a firm can serve any market by any of its affiliate via trade. To the extent possible, I use the following indexing conventions : index $i$ denotes the country where

[6] The works include but not limited to Zodrow and Mieszkowski (1986), Wilson (1986), and Gordon and Hines (2002). Keen and Konrad (2014) provides an excellent summary of these models.

the firm originates, index $\ell$ denotes the country where the product is manufactured, and index $n$ denotes the destination country where the good is consumed.

There are frictions for MP and trade. As in ARRY (2018), firms originated in country $i$ that produce in country $\ell$ incurs an iceberg MP cost $\gamma_{i\ell} \geq 1$ with $\gamma_{ii} = 1$. Moreover, firms that export from country $\ell$ to country $n$ incurs a fixed marketing cost $F_n$ in terms of labor in the destination country, and an iceberg trade cost $\tau_{\ell n} \geq 1$ with $\tau_{nn} = 1$.

There are $\bar{L}_i$ workers in country $i$. Workers are immobile across countries but mobile across activities (innovation and production/marketing) within each country. Following Roy (1951), I assume that each worker is endowed with $\nu^e$ units of labor for innovation and $\nu^p$ units of labor for production or marketing. I denote the wage per unit of labor for innovation by $w_i^e$ and the wage per unit of labor for production or marketing by $w_i^p$. As in Arkolakis et al. (2018), $\nu^e = u^e/\Gamma(1-1/\mu)$ and $\nu^p = u^p/\Gamma(1-1/\mu)$, with $u^e$ and $u^p$ both drawn independently from the distribution $\exp[-u^{-\mu}]$, where $\mu > 1$ and where $\Gamma(.)$ is the Gamma function.

The production technology in the model can be summarized by the unit cost for a firm that originates from country $i$ and produces in country $\ell$ to serve market $n$:

$$c_{i\ell n}(\omega) = \frac{\xi_{i\ell n}}{\varphi_i(\omega) z_\ell(\omega)}, \quad \text{where } \xi_{i\ell n} = \gamma_{i\ell} w_\ell^p \tau_{\ell n}, \tag{1}$$

and where the labor productivity consists of two parts: (i) $\varphi_i(\omega)$ is the core productivity of firm $\omega$ that can be utilized in any of its affiliate, and (ii) $z_\ell(\omega)$ is the productivity that is specific to its affiliate in country $\ell$.

For model's tractability, I assume the timing of events summarized by Figure 1. Post entry, the firm draws its core productivity, and then decides which countries to serve and pays the marketing fixed costs. Then the firm observes its production-site-specific productivities ($z_\ell$) and decides its production locations.[7]

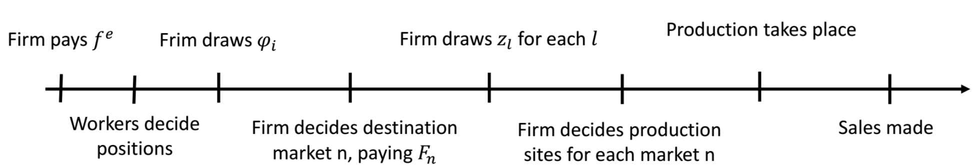



Figure 1: The Timing of Events

[7]Following ARRY (2018), I assume that there is no fixed cost in establishing a production site. This assumption leads to an analytical gravity equation of trade and MP flows.

As in Melitz (2003), the core productivity, $\varphi_i(\omega)$, is drawn from a Pareto distribution:

$$Pr(\varphi_i(\omega) \leq \varphi) = G_i(\varphi) = 1 - T_i \varphi^{-\theta}, \quad \varphi \geq T_i^{\frac{1}{\theta}}, \quad \theta > \max\{\sigma - 1, 1\}. \tag{2}$$

The vector of production-site-specific productivities $\{z_{i\ell}(\omega)\}$ is drawn independently across firms from a multivariate Frechet distribution:

$$Pr(\{z_{i\ell}(\omega) \leq z_\ell\}_{\ell=1}^N) = \exp\left\{ - \left[ \sum_{\ell \neq i} \left( A_\ell z_\ell^{-\epsilon} \right)^{\frac{1}{1-\rho}} \right]^{1-\rho} - A_i z_i^{-\epsilon} \right\}, \quad z > 0, \quad \epsilon > \theta, \quad \rho \in [0,1), \tag{3}$$

where $A_\ell$ is the level of production productivity in $\ell$ and $\epsilon$ characterizes the dispersion of productivities across potential production sites. A large $\epsilon$ implies that the distribution of production-site-specific productivities is concentrated, leading to small responses of MP entry with respect to changes in trade and MP frictions.

A novel feature of the multivariate Frechet distribution in Equation (3), comparing to the one used in Ramondo and Rodriguez-Clare (2013), is that it allows productivity draws in two foreign production sites to be more correlated than draws in a foreign site and the domestic site. This feature captures a long-noticed insight that foreign firms are more footloose than domestic firms in deciding production sites. In the special case where $\rho = 0$, the multivariate Frechet distribution in Equation (3) is identical to the one in Ramondo and Rodriguez-Clare (2013), which makes the production technology in this paper isomorphic to the one in ARRY (2018). However, when $\rho \to 1$, foreign production sites become perfectly substitute for a multinational firm, which makes it extremely footloose in choosing its foreign production sites. In contrast, a multinational firm is less likely to replace its domestic affiliate by its foreign affiliates since the domestic productivity draw is uncorrelated with foreign productivity draws. In Section 3, I will show that the parameter $\rho$ is important in shaping governments' incentives for manipulating corporate taxes.

## 2.2 Corporate Taxes

In this subsection, I derive the firms' profits conditional on their production sites and specify corporate income taxation. The standard results for monopolistic competition imply that the *pre-tax* profits of firm $\omega$ from country $i$ serving market $n$ from its plant in country $\ell$ can be expressed as

$$\pi_{i\ell n}(\omega) = \frac{1}{\sigma} \tilde{\sigma}^{1-\sigma} c_{i\ell n}(\omega)^{1-\sigma} X_n P_n^{\sigma-1}, \quad \tilde{\sigma} = \frac{\sigma}{\sigma - 1}, \tag{4}$$

where $X_n$ is the total expenditure of country $n$, and $P_n$ is the price index in country $n$. I assume that the profit in Equation (4) is subject to corporate taxes, implying that the fixed marketing cost $F_n$ is not tax-deductible. Although not fully realistic, this assumption makes the model tractable and the estimation transparent.[8] Moreover, since $F_n$ is common for all firms serving market $n$ regardless of where they produce, this assumption should have very little impacts on firms' location choices and aggregate MP flows.

The corporate tax system in my model is an abstraction of the complex international corporate tax architecture in the real world.[9] Consider a firm with its headquarters located in country $i$. The profits made by its affiliate in country $\ell$ are subject to the local corporate income tax before it can be paid out as dividend. I denote the *local corporate tax* rate in country $\ell$ as $ct_\ell$, which is identical for all firms operating in country $\ell$. For a domestic firm located in country $\ell$, this local corporate tax is the only tax on income paid out as dividends at the corporate level.

When post-tax corporate income is paid out as dividends from host country $\ell$ to source country $i$, it is subject to a *nonresident dividend withholding (NRDW) tax*, $nrdw_{i\ell}$, levied by the host country. This tax is an additional tax at the corporate level on account of foreign ownership. Notice that $nrdw_{i\ell}$ is source-country-specific, meaning that the host country can effectively impose different corporate tax rates to MNEs from different source countries. According to Huizinga, Voget, and Wagner (2014), all 38 major countries levy source-country-specific corporate taxes. In practice, NRDW tax rates are often determined by bilateral tax treaties.

In the quantification, I consider the local corporate tax rate $ct_\ell$ and NRDW tax rates $(nrdw_{i\ell})_{i=1}^N$ as the policy tools for country $\ell$'s government. Equivalently, the government of country $\ell$ decides a vector of tax rates, $(\tilde{\kappa}_{i\ell})_{i=1}^N$, which consists of corporate tax rates for firms originated from countries $i = 1, \ldots, N$:

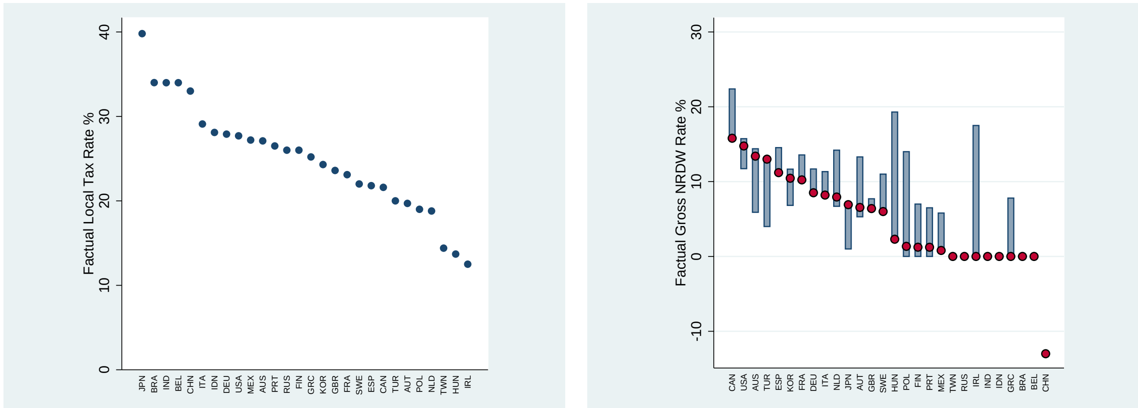
$$\tilde{\kappa}_{i\ell} := ct_\ell + \underbrace{(1 - ct_\ell) \times nrdw_{i\ell}}_{\textbf{gross NRDW rate}}. \tag{5}$$

Figure 2 illustrates the corporate tax rates[10] across 28 countries in 2007. Patterns in

[8] As shown below, when $F_n$ is not tax-deductible, the corporate taxes are equivalent to iceberg MP costs in deciding firms' production locations.

[9] The international corporate tax system in reality has been characterized in detail by Huizinga and Voget (2009) and Huizinga, Voget, and Wagner (2014).

[10] The tax data combines the effective local tax rates in PwC Global Effective Tax Rates and KPMG's Corporate and Indirect Tax Rate Survey with the statutory NRDW tax rates in Huizinga, Voget, and Wagner (2014). The details of data construction are discussed in Section 4.2.




(a) Local

(b) Gross NRDW

Figure 2: Corporate Tax Rates in 2007

(Notes: In Panel (b), the dot refers to the median of the gross NRDW rates. The upper bar of the box refers to the 75 quantile of the gross NRDW tax rates and the lower bar of the box refers to the 25 quantile of the Gross NRDW rates.)

the data are consistent with the specification of corporate taxes in my model: Panel (a) of Figure 2 shows that local corporate tax rates vary considerably across countries, ranging from 12.5% for Ireland to 39.8% for Japan. Panel (b) of Figure 2 suggests that the gross NRDW rates are sizable[11] and vary substantially across source countries in most of the host countries. In other words, countries do levy source-country-specific corporate taxes.

In reality, dividends earned abroad can also be subject to taxes in the MNEs' source country (e.g. the United States). In this paper, I do not consider these residence-based taxes collected by source countries because they are less prevalent and smaller in size than the taxes collected by host countries (See Huizinga and Voget (2009) and Huizinga, Voget, and Wagner (2014) for the summary). Moreover, in Section B.7, I incorporate residence-based corporate taxes into the model and compute the unilaterally optimal corporate tax rates in the U.S., finding that the residence-based taxation has very little impacts on the U.S. welfare gains from optimal taxes.

## 2.3 Profit Shifting and Tax Avoidance

Profit shifting as a way of tax avoidance has drawn an increasing attention from policy makers in designing corporate tax systems for MNEs. This model characterizes the firms' profit shifting by the following simple manner. Suppose that firm $\omega$ from country $i$ producing

[11] China is an exception. In 2007, China's statutory corporate tax rate for Chinese domestic firms was 33%. However, the statutory corporate tax rate for foreign MNE affiliates operating in China was 20%. China subsidized foreign MNEs by lowering their corporate tax rates. After 2008, China's statutory corporate tax rate is 25% for all firms operating in China.

in country $\ell$ and making sales to country $n$ earns a pre-tax profit $\pi_{i\ell n}(\omega)$. It can potentially shift a fraction $s$ of this profit to country $k$, incurring a cost in the form $\frac{1}{2}\eta_{i\ell k}s^2\pi_{i\ell n}(\omega)$.[12] Notice that $\eta_{i\ell k} > 0$ determines the cost of profit-shifting, which depends on the source country $i$, the host country $\ell$, and the tax haven country $k$.

Given corporate tax rates ($\tilde{\kappa}_{i\ell}$) and profit-shifting costs ($\eta_{i\ell k}$), the optimal profit-shifting can be solved by

$$\max_{s_k\in[0,1]} \sum_{k=1}^{N} \left[ (1-s_k)(1-\tilde{\kappa}_{i\ell})\pi_{i\ell n}(\omega) + s_k(1-\tilde{\kappa}_{ik})\pi_{i\ell n}(\omega) - \frac{1}{2}\eta_{i\ell k}s_k^2\pi_{i\ell n}(\omega) \right]. \tag{6}$$

The optimal share of profit-shifting is thereby given by

$$s^*_{i\ell k} = \begin{cases} 0 & \text{if } \frac{\tilde{\kappa}_{i\ell}-\tilde{\kappa}_{ik}}{\eta_{i\ell k}} < 0 \\ \frac{\tilde{\kappa}_{i\ell}-\tilde{\kappa}_{ik}}{\eta_{i\ell k}} & \text{if } \frac{\tilde{\kappa}_{i\ell}-\tilde{\kappa}_{ik}}{\eta_{i\ell k}} \in [0,1] \end{cases} \tag{7}$$

The interior solution requires that $\sum_k s^*_{i\ell k} \leq 1$ for all $(i,\ell)$. I assume that $\eta_{i\ell k}$ are sufficiently large so that this constraint is never binding.

How does the profit-shifting cost, $\eta_{i\ell k}$, depend on the source country $i$, destination country $\ell$, and tax haven country $k$? There is an extensive discussion in the literature about the fact that MNEs utilize their affiliates in low-tax countries as vehicles for profit shifting and tax avoidance. To incorporate this idea into my structural settings, I connect the profit-shifting cost to bilateral MP flows:

$$\eta_{i\ell k} = \frac{\tilde{\eta}}{\lambda^{MP}_{ik}}, \quad \text{where } \lambda^{MP}_{ik} = \frac{X^{MP}_{ik}}{\sum_{k'} X^{MP}_{ik'}}, \tag{8}$$

and where $X^{MP}_{ik}$ is the total value of production of firms originated from country $i$ in country $k$.

The profit-shifting cost in Equation (8) is worth further discussion. First, if firms originated from country $i$ do not have affiliates in tax haven country $k$, i.e. $\lambda^{MP}_{ik} = 0$, then they cannot shift their profits into country $k$ since $\eta_{i\ell k} = \infty$. Second, for model's tractability, I assume that $\eta_{i\ell k}$ depends on the total sales of firms originated from country $i$ in tax haven $k$, not on the individual affiliate sales of a firm originated from country $i$ in $k$. Equation (8) essentially assumes that having larger MP sales in tax haven $k$ makes firms originated from country $i$ *on average* incur lower costs in shifting profits to country $k$, which captures

[12] I assume that this profit-shifting cost is earned by the host country $\ell$ since usually it is costly to send profits out.

the key feature of international profit shifting.[13] My model implies, for example, as the U.S. has larger MP in the Netherlands, the U.S. MNEs can shift a larger fraction of the profits earned by their Japanese affiliates to the Netherlands.

The post-tax profits of firm $\omega$ originated from country $i$ to serve market $n$ from its plant in country $\ell$ is thereby:

$$\tilde{\pi}_{i\ell n}(\omega) = \sum_{k=1}^{N} \left[ (1-\tilde{\kappa}_{i\ell}) + (\tilde{\kappa}_{i\ell} - \tilde{\kappa}_{ik}) \max\left\{ \frac{\tilde{\kappa}_{i\ell} - \tilde{\kappa}_{ik}}{\eta_{i\ell k}}, 0 \right\} - \frac{1}{2}\eta_{i\ell k} \max\left\{ \frac{\tilde{\kappa}_{i\ell} - \tilde{\kappa}_{ik}}{\eta_{i\ell k}}, 0 \right\}^2 \right] \pi_{i\ell n}(\omega). \tag{9}$$

## 2.4 The Firm's Problem

In this subsection, I characterize the firm's problem of global production and sales. Firm $\omega$ from country $i$ will serve market $n$ if and only if

$$E_{(z_\ell(\omega))} \left[ \sum_{i=1}^{N} \tilde{\pi}_{i\ell n}(\omega) \right] \geq w_n^p F_n.$$

Now I specify the firm's problem in choosing its production sites. Equation (9) suggests that corporate taxation is equivalent to an increase in firms' unit costs, the extend of which is given by

$$\kappa_{i\ell} = \left\{ \sum_{k=1}^{N} \left[ (1-\tilde{\kappa}_{i\ell}) + (\tilde{\kappa}_{i\ell} - \tilde{\kappa}_{ik}) \max\left\{ \frac{\tilde{\kappa}_{i\ell} - \tilde{\kappa}_{ik}}{\eta_{i\ell k}}, 0 \right\} - \frac{1}{2}\eta_{i\ell k} \max\left\{ \frac{\tilde{\kappa}_{i\ell} - \tilde{\kappa}_{ik}}{\eta_{i\ell k}}, 0 \right\}^2 \right] \right\}^{\frac{1}{1-\sigma}}. \tag{10}$$

Then a firm originated from country $i$ will choose its production location to serve market $n$ by minimizing its tax-adjusted unit cost:

$$\ell(\omega) = \arg \min_{k=1,\ldots,N} \left\{ \kappa_{ik} \frac{\xi_{ikn}}{z_k(\omega)} \right\}. \tag{11}$$

Equation (11) indicates that a firm decides its production sites based on the effective cost shifter of taxation, ($\kappa_{i\ell}$), together with production-site-specific productivities, wages in the host countries, and trade and MP frictions.

[13] Guvenen et al. (2018) suggest that the U.S. MNEs shift their profits to countries such as Canada, the U.K., Ireland, the Netherlands, Bermuda, and Switzerland. Most of these countries are also main host countries for the U.S. MNEs.

## 2.5 Aggregate Trade and MP Flows

In this subsection, I solve the firm's choices of production sites and destination markets and aggregate these decisions to solve for the general equilibrium. Let $\zeta_{i\ell n}$ be the probability that a firm originated from country $i$ serves country $n$ by its affiliate at country $\ell$. Utilizing the property of multivariate Frechet distribution, I have[14]

$$\begin{aligned}\zeta_{iin} &= \frac{A_i(\xi_{iin}\kappa_{ii})^{-\epsilon}}{\left[\sum_{k\neq i} A_k(\xi_{ikn}\kappa_{ik})^{-\frac{\epsilon}{1-\rho}}\right]^{1-\rho} + A_i(\xi_{iin}\kappa_{ii})^{-\epsilon}},\\ \zeta_{i\ell n} &= \frac{\left[\sum_{k\neq i} A_k(\xi_{ikn}\kappa_{ik})^{-\frac{\epsilon}{1-\rho}}\right]^{1-\rho}}{\left[\sum_{k\neq i} A_k(\xi_{ikn}\kappa_{ik})^{-\frac{\epsilon}{1-\rho}}\right]^{1-\rho} + A_i(\xi_{iin}\kappa_{ii})^{-\epsilon}} \frac{A_\ell(\xi_{i\ell n}\kappa_{i\ell})^{-\frac{\epsilon}{1-\rho}}}{\sum_{k\neq i} A_k(\xi_{ikn}\kappa_{ik})^{-\frac{\epsilon}{1-\rho}}}, \quad \ell \neq i.\end{aligned} \tag{12}$$

Notice that the corporate tax is an income tax which does not directly affect individual prices. In other words, the corporate tax affects a firm's choices for production sites, but not its prices *conditional on* production sites. As a result, the probability that a firm originated from country $i$ will serve country $n$ by its affiliate at country $\ell$ is not equal to the share of pre-tax sales for firms from $i$ to $n$ through $\ell$.

Let $X_{i\ell n}$ be the pre-tax sales of firms from country $i$ to country $n$ from their affiliates in country $\ell$.[15] Let $X_{in}$ be the total pre-tax sales of firms from country $i$ to country $n$. Then

$$\begin{aligned}\psi_{i\ell n} &:= \frac{X_{i\ell n}}{X_{in}} = \frac{\zeta_{i\ell n}\kappa_{i\ell}^{\sigma-1}}{\sum_{k=1}^N \zeta_{ikn}\kappa_{ik}^{\sigma-1}}\\ \Rightarrow \psi_{iin} &= \frac{A_i(\xi_{iin}\kappa_{ii})^{-\epsilon}\kappa_{ii}^{\sigma-1}}{\left[\sum_{k\neq i} A_k(\xi_{ikn}\kappa_{ik})^{-\frac{\epsilon}{1-\rho}}\right]^{-\rho} \sum_{k\neq i} A_k(\xi_{ikn}\kappa_{ik})^{-\frac{\epsilon}{1-\rho}}\kappa_{ik}^{\sigma-1} + A_i(\xi_{iin}\kappa_{ii})^{-\epsilon}\kappa_{ii}^{\sigma-1}},\\ \psi_{i\ell n} &= \frac{\left[\sum_{k\neq i} A_k(\xi_{ikn}\kappa_{ik})^{-\frac{\epsilon}{1-\rho}}\right]^{-\rho} A_\ell(\xi_{i\ell n}\kappa_{i\ell})^{-\frac{\epsilon}{1-\rho}}\kappa_{i\ell}^{\sigma-1}}{\left[\sum_{k\neq i} A_k(\xi_{ikn}\kappa_{ik})^{-\frac{\epsilon}{1-\rho}}\right]^{-\rho} \sum_{k\neq i} A_k(\xi_{ikn}\kappa_{ik})^{-\frac{\epsilon}{1-\rho}}\kappa_{ik}^{\sigma-1} + A_i(\xi_{iin}\kappa_{ii})^{-\epsilon}\kappa_{ii}^{\sigma-1}}, \quad \ell \neq i.\end{aligned} \tag{13}$$

Rewriting Equation (12), I have $\zeta_{i\ell n} = \frac{\psi_{i\ell n}\kappa_{i\ell}^{1-\sigma}}{\sum_{k=1}^N \psi_{ikn}\kappa_{ik}^{1-\sigma}}$. Notice that if $\kappa_{i\ell} = 1$ for all $(i, \ell)$ as in ARRY (2018), then $\psi_{i\ell n} = \zeta_{i\ell n}$.

Similarly, the corporate tax affects the expected unit cost of firm $\omega$ from country $i$ to

[14] The algebra is presented in detail in Appendix A.1.

[15] Since I assume that profit-shifting is only for tax avoidance, it does not affect pre-tax sales.

serve market $n$ only through its choice of production sites. For convenience, I define

$$\begin{aligned}\Phi_{in} &= \left\{ \left[ \sum_{k \neq i} A_k (\xi_{ikn} \kappa_{ik})^{-\frac{\epsilon}{1-\rho}} \right]^{1-\rho} + A_i (\xi_{iin} \kappa_{ii})^{-\epsilon} \right\}^{-\frac{1}{\epsilon}}, \\ \Psi_{in} &= \sum_{k=1}^{N} \zeta_{ikn} \kappa_{ik}^{\sigma-1},\end{aligned} \tag{14}$$

where $\Phi_{in}$ is the the post-tax expected cost of firms from country $i$ to serve country $n$, and $\Psi_{in}$ adjusts the corporate taxes. The expected unit cost of firm $\omega$ originated from country $i$ to serve market $n$ is given by

$$c_{in}(\omega) = E_z(\min_{\ell}\{c_{i\ell n}(\omega)\}) = \frac{\tilde{\gamma}}{\varphi_i(\omega)} \Phi_{in} \Psi_{in}^{\frac{1}{1-\sigma}}, \tag{15}$$

where $\tilde{\gamma}$ is constant.

The pre-tax sales of firms originated from $i$ to market $n$, $X_{in}$, is determined by their pre-tax expected costs:

$$\lambda_{in} := \frac{X_{in}}{X_n} = \frac{M_i T_i \Phi_{in}^{-\theta} \Psi_{in}}{\sum_{h=1}^{N} M_h T_h \Phi_{hn}^{-\theta} \Psi_{hn}}, \tag{16}$$

where $M_i$ is the mass of firms in country $i$. Intuitively, the sales of firms originating from country $i$ in country $n$ increases with respect to the mass of firms in country $i$ and decreases with respect to the expected unit serving costs.

The price index in country $n$ is determined by the expected unit serving costs from all home countries:

$$P_n^{-\theta} = \frac{\theta \sigma^{-\frac{\theta-(\sigma-1)}{\sigma-1}} \tilde{\gamma}^{-\theta} \tilde{\sigma}^{-\theta}}{\theta - (\sigma - 1)} \left[ \frac{w_n^p F_n}{X_n} \right]^{-\frac{\theta-(\sigma-1)}{\sigma-1}} \sum_{i=1}^{N} M_i T_i \Phi_{in}^{-\theta} \Psi_{in}. \tag{17}$$

## 2.6 Equilibrium

In this subsection, I define the general equilibrium in my model. The aggregation in the previous subsection delivers the following expression for the pre-tax "trilateral" trade flows:

$$X_{i\ell n} = \psi_{i\ell n} \lambda_{in} X_n. \tag{18}$$

Moreover, monopolistic competition and Pareto distribution of core productivity imply that the total fixed marketing cost associated with the sales of firms originated from country $i$ to market $n$ equals to $\delta\frac{X_{in}}{\Psi_{in}}$ where $\delta=\frac{\theta-(\sigma-1)}{\theta\sigma}$.

The incomes and expenditure can then be expressed by aggregate trade and MP flows. First, the wage income for production/marketing workers in country $i$ can be expressed as

$$w_i^p L_i^p = \left(1-\frac{1}{\sigma}\right)\sum_{k,n} X_{kin} + \delta \sum_{k} \frac{X_{ki}}{\Psi_{ki}}. \tag{19}$$

The wage income for innovation workers is equal to firms' post-tax profits:

$$w_i^e L_i^e = M_i w_i^e f^e = \sum_{\ell,n}\left[\frac{1}{\sigma}\kappa_{i\ell}^{1-\sigma} X_{i\ell n} - \delta\zeta_{i\ell n}\frac{X_{in}}{\Psi_{in}}\right]. \tag{20}$$

Total income of an agent equals her wage income plus tax revenues transfered by the government. I assume that corporate tax revenues are evenly allocated to domestic workers through lump-sum transfers. The aggregate expenditure in country $i$ is then:

$$X_i = w_i^p L_i^p + w_i^e L_i^e + \Lambda_i, \tag{21}$$

where

$$\begin{aligned}\Lambda_\ell =& \sum_{i,k,n}\frac{1}{\sigma}\tilde{\kappa}_{i\ell}\left(1-\max\left\{\frac{\tilde{\kappa}_{i\ell}-\tilde{\kappa}_{ik}}{\eta_{i\ell k}},0\right\}\right)X_{i\ell n}\\ &+\sum_{i,k,n}\frac{1}{2}\eta_{i\ell k}\max\left\{\frac{\tilde{\kappa}_{i\ell}-\tilde{\kappa}_{ik}}{\eta_{i\ell k}},0\right\}^2\frac{1}{\sigma}X_{i\ell n}\\ &+\sum_{i,k,n}\frac{1}{\sigma}\tilde{\kappa}_{i\ell}\max\left\{\frac{\tilde{\kappa}_{ik}-\tilde{\kappa}_{i\ell}}{\eta_{ik\ell}},0\right\}X_{ikn}.\end{aligned} \tag{22}$$

is the tax revenue in country $i$.[16]

Finally, I solve labor allocation within country. Workers choose to work in the position that gives them the highest utility. The properties of Frechet distribution indicate that

$$\frac{L_i^e}{\bar{L}_i} = \left[1+\left(\frac{w_i^e}{w_i^p}\right)^{-\mu}\right]^{\frac{1}{\mu}-1}, \tag{23}$$

and

$$\frac{L_i^p}{\bar{L}_i} = \left[1+\left(\frac{w_i^e}{w_i^p}\right)^{\mu}\right]^{\frac{1}{\mu}-1}. \tag{24}$$

[16] Notice that I have assumed that the profit-shifting cost is earned by the host country. To save notations, I include the profit-shifting cost into the tax revenue.

The general equilibrium can be defined as follows:

**Definition 1** *Given* $(T_i, L_i, A_i, \tau_{\ell n}, \gamma_{i\ell}, f^e; \theta, \epsilon, \rho, \sigma, \mu; \eta_{i\ell k})$ *and* $(\tilde{\kappa}_{i\ell})$*, the equilibrium consists of* $(w_i^p, w_i^e, P_i, X_i, L_i^p, L_i^e, M_i, \kappa_{i\ell})$ *such that*

1. *The effective cost shifter of taxation,* $(\kappa_{i\ell})$*, is given by Equation (10).*

2. $w_i^p$ *satisfies labor market clearing condition (19).*

3. $X_i$ *is given by the current account balance condition (21).*

4. $w_i^e$ *and* $M_i$ *is determined by free entry condition (20).*

5. $L_i^p$ *and* $L_i^e$ *are determined by labor allocation in Equation (23) and (24).*

6. $P_i$ *is given by the price equation (17).*

Notably, since the preference is homothetic, the welfare of country $i$ can be measured by its real income:

$$W_i = \frac{X_i/\bar{L}_i}{P_i} = \frac{[(w_i^e)^\mu + (w_i^p)^\mu]^{\frac{1}{\mu}} + \Lambda_i/\bar{L}_i}{P_i}. \tag{25}$$

Throughout this paper, I assume that the government manipulates corporate taxes in order to maximize the welfare of its own country. This assumption creates a useful benchmark in understanding the determination of corporate taxes, which is in line with the literature of commercial policies.[17]

## 2.7 Equilibrium in Relative Changes

Definition 1 presents a system of $6N+N^2$ equations in the $6N+N^2$ unknowns $w_i^p$, $w_i^e$, $P_i$, $X_i$, $L_i^p$, $M_i$, and $\kappa_{i\ell}$, which can be solved given a numeraire. However, this system depends on a large number of unknown parameters $(A_i, T_i, \gamma_{i\ell}, \tau_{\ell n})$, which are difficult to estimate empirically.

To avoid this problem, I compute the changes of equilibrium outcomes with respect to changes in corporate tax rates using the "exact-hat" algebra developed by Dekle, Eaton, and Kortum (2007). Let $y'$ be the level of variable $y$ after change and $\hat{y} := y'/y$. Armed with the parameters $(\theta, \epsilon, \rho, \mu, \sigma, \tilde{\eta})$ and data on $(X_{i\ell n}, \tilde{\kappa}_{i\ell})$, I can solve the changes in equilibrium outcomes, $(\hat{w}_i^p, \hat{w}_i^e, \hat{X}_i, \hat{L}_i^p, \hat{P}_i, \hat{M}_i, \hat{\kappa}_{i\ell})$, with respect to changes in $(\tilde{\kappa}_{i\ell})$. The details are presented in Appendix A.2.

[17] See, for example, Ossa (2014, 2016).

# 3 Welfare Implications of Corporate Taxation

In this section, I characterize the welfare implications of corporate taxation in the presence of MP. I restrict my analysis to special cases that can be explored analytically or through simple numerical examples. These cases illustrate how, in the presence of MP, different elements of my model shape the governments' incentives for manipulating corporate taxes, providing intuitive guidances on my quantitative analysis in Section 5 and 6.

## 3.1 Corporate Taxation under Autarky

To understand the efficiency of the equilibrium, it is instructive to consider the case in which trade and MP costs are infinite. In this case, the welfare-maximizing corporate tax is given by:

**Proposition 2 (Autarky)** *Let $\tilde{\kappa}^*$ be the corporate tax rate that maximizes the welfare of a closed-economy. Then*

$$\tilde{\kappa}^* = 0.$$

Proposition 2 indicates that in a closed economy the welfare-maximizing government should not collect corporate taxes. This is not surprising since Dixit and Stiglitz (1977) shows that this monopolistic competition equilibrium is constrained efficient. Therefore, to rationalize non-zero corporate taxes in this setting, it must be in an open economy where a country can manipulate its corporate taxes to gain at the expenses of other countries.

## 3.2 Welfare Effects of Corporate Taxes in a Two-Country World

In a global economy with trade and MP, it may no longer be optimal for a country to impose no corporate taxes. In this subsection, I characterize analytically in a two-country world the impacts of a country's corporate taxes on the welfare of itself and the other country. The purpose is to understand the motives for a country to manipulate its corporate taxes in order to gain at the expense of others. For this analytical characterization, I consider the following simple setting.

**Proposition 3** *Consider a world with two countries ($i = 1, 2$). Assume no trade and MP costs ($\gamma_{i\ell} = \tau_{\ell n} = 1$), perfect labor mobility across positions ($\mu \to \infty$), no profit shifting ($\eta_{i\ell k} = \infty$), no effect of higher income on price indices ($\theta \to \sigma - 1$), and symmetric technology and country size ($A_i = T_i = \bar{L}_i = 1$). Let $w_1 = 1$. Evaluating at the point in which* $(\kappa_{11}, \kappa_{21}) = (1, 1)$*, I have:*

1. *The home market effects in innovation:*

$$\frac{\partial \log(M_1)}{\partial \kappa_{21}} > 0, \quad \frac{\partial \log(M_1)}{\partial \kappa_{11}} < 0; \quad \frac{\partial \log(M_2)}{\partial \kappa_{21}} < 0, \quad \frac{\partial \log(M_2)}{\partial \kappa_{11}} > 0. \tag{26}$$

2. *The terms-of-trade effects:*

$$\frac{\partial \log(w_2)}{\partial \kappa_{21}} < 0, \quad \frac{\partial \log(w_2)}{\partial \kappa_{11}} > 0. \tag{27}$$

3. *The welfare effects:*

$$\frac{\partial \log(W_1)}{\partial \kappa_{21}} > 0, \quad \frac{\partial \log(W_1)}{\partial \kappa_{11}} < 0; \quad \frac{\partial \log(W_2)}{\partial \kappa_{21}} < 0, \quad \frac{\partial \log(W_2)}{\partial \kappa_{11}} > 0. \tag{28}$$

A key implication of Proposition 3 is that the corporate taxation has multiple channels to affect the welfare in two countries. The first result of Proposition 3 captures a *home market effect in innovation*. In particular, firms tend to create differentiated goods ("innovate") in a country that has low barriers to outward MP but high barriers to inward MP. By taxing foreign firms and subsidizing domestic firms, country 1 effectively increases its inward MP cost, inducing firm entry and thereby promoting its innovation. Since innovation exhibits increasing returns to scale and generates profit flows back to country 1, moving labor from production (a constant-return-to-scale activity) to innovation leads to welfare gains in country 1.

The home market effect in innovation is essentially the result (ii) of Proposition 2 in ARRY (2018) in which, other things equal, a country will specialize in innovation if its inward MP cost is larger than its outward MP cost. This result is also in line with the home market effect of tariffs emphasized by Ossa (2011) in which a unilateral increase in import tariffs triggers firm entry into domestic manufacturing sector and exit out of the foreign manufacturing sector. In this paper, it is *MP* costs instead of *trade* costs that shape the distribution of innovation across countries.

The second result of Proposition 3 captures *a terms-of-trade effect*. In particular, the relocation of firms to country 1 increases labor demand in country 1 relative to country 2 so that country 1's wage increases relative to country 2. The increase in the relative wage of country 1 directly translates into the increase in the prices of goods made in country 1 relative to the goods made in country 2 which amounts to an improvement in country 1's terms-of-trade.

The third result of Proposition 3 suggests that due to the home market effect in innovation and the terms-of-trade effect discussed above, country 1 gains from subsidizing domestic firms and taxing foreign firms, at the expense of country 2. This result implies the unilaterally optimal NRDW tax rate should be strictly positive.

## 3.3 Optimal Corporate Taxation in Special Cases

What are the corporate taxes a country will levy if it does not have to fear retaliation from other countries? How do these optimal taxes rely on key elements of my model? Lack of analytical solutions, I will investigate optimal corporate taxes using simple numerical examples.

I begin by solving the unilaterally optimal corporate tax rates in the two-country example discussed in Section 3.2, letting $\mu = 3$, $\theta = \sigma = 4$, and $\epsilon = 6$.[18] The optimal corporate tax rates for country 1 is $(\tilde{\kappa}^*_{11}, \tilde{\kappa}^*_{21}) = (0.0678, 0.4692)$. Consistent with Proposition 3, the optimal corporate tax rate for foreign firms is much higher than for domestic firms. The optimal local corporate tax rate in this case is strictly positive because this tax is partially borne by production workers in the country 2 but all tax revenues go to country 1. Another way to look at this is that an increase in country 1's local corporate tax rate will reduce the its affiliate sales in country 2, which decreases the labor demand in country 2 and thereby improves country 1's terms-of-trade.

**Openness to MP**– How does the openness to foreign MNEs affect a country's incentives to manipulate its corporate taxes? Resorting to the two-country example above and increasing $\gamma_{12} = \gamma_{21} = \gamma$ symmetrically, I find that as a country becomes less open to MP, it will lower its local corporate tax rate but raise its gross NRDW tax rate.[19] This result can be explained by the home market effect in innovation. In particular, country 1 gains more from the larger number of varieties created by its domestic firms than it loses from the smaller number of varieties produced by foreign firms because the profits of foreign firms are owned by foreign innovation workers. As $\gamma$ goes larger, domestic firms become increasingly important to country 1 and therefore country 1 gains more from protecting these firms.

**Specialization in innovation/production**– How do a country's optimal corporate tax rates depend on its comparative advantage in innovation or production? I turn again to the two-country example, letting $\gamma_{i\ell} = \tau_{\ell n} = 1.2$ for all $i \neq \ell$ and $\ell \neq n$ and increasing $A_1$ from 1 to 2. As $A_1$ goes larger, country 1 further specializes in production. I find that

[18]Under $\mu = \infty$, the optimal tax rates would lead to complete specialization equilibrium in which $M_2 = 0$. To obtain interior solutions, I set $\mu = 3$ in this numerical example. The details of parameters and computation are presented in Appendix A.5.

[19]See Figure A.3 in the appendix for illustration.

the optimal local tax rate in country 1 is decreasing with $A_1$, whereas the optimal gross NRDW tax rate in country 1 is increasing with $A_1$.[20] With stronger comparative advantage in production, country 1 gains more from inducing the entry of its domestic firms because the varieties created by domestic firms are more likely to be produced domestically.[21]

**Elasticity to Taxes–** I proceed by investigating the role of two parameters governing how firms relocate their plants in response to changes in corporate taxes: (i) $\epsilon$ determines how footloose a firm is in deciding its production sites between two countries; and (ii) $\rho$ determines how footloose a MNE is in deciding its production site between two *foreign* countries. I consider a three-country example ($N = 3$)[22] with $\gamma_{i\ell} = \tau_{\ell n} = 1.2$ for all $i \neq \ell$ and $\ell \neq n$, $A_i = T_i = \bar{L}_i = 1$ for all $i$, no profit shifting ($\tilde{\eta} = \infty$), $\theta = \sigma = 4$, $\epsilon = 6$, and $\rho = 0.2$. I compute the optimal corporate tax rates for domestic and foreign firms in country 1 under different values of $\epsilon$ and $\rho$.

The numerical results show that as $\epsilon$ or $\rho$ increases, the optimal gross NRDW tax rate *decreases* considerably, whereas the optimal local corporate tax rate is largely unchanged.[23] This result is in line with the classical analysis of optimal taxation: use low rates where the base is more elastic to the rate. As firms become more footloose among potential production sites, the high gross NRDW tax rate will substantially reduce the entry of foreign MNE affiliates and decrease the labor demand in the host country.

**Profit Shifting–** Finally, I examine how profit shifting affects the optimal corporate taxes. I turn to the three-country example discussed above. Figure 3 illustrates the optimal statutory and effective corporate taxes for foreign firms with respect to the profit shifting cost, $\tilde{\eta}$. As $\tilde{\eta}$ falls, the government tends to increase its statutory corporate tax rate for foreign firms in order to maintain its effective tax rate. However, the government will not raise its statutory tax rate to the level that keeps the effective corporate tax rate unchanged because doing so will dramatically increase the profit shifted to foreign countries. Consequently, the optimal effective corporate tax rate for foreign MNEs would decrease as profit shifting becomes less costly for these firms.

[20]See Figure A.5 in the appendix for illustration.

[21]In contrast, if a country has comparative disadvantage in production, the varieties created by its domestic firms are likely to be produced abroad, which benefits other countries.

[22]For $\rho$ being relevant, there should be at least two *foreign* countries.

[23]See Figure A.7 in the appendix for illustration.

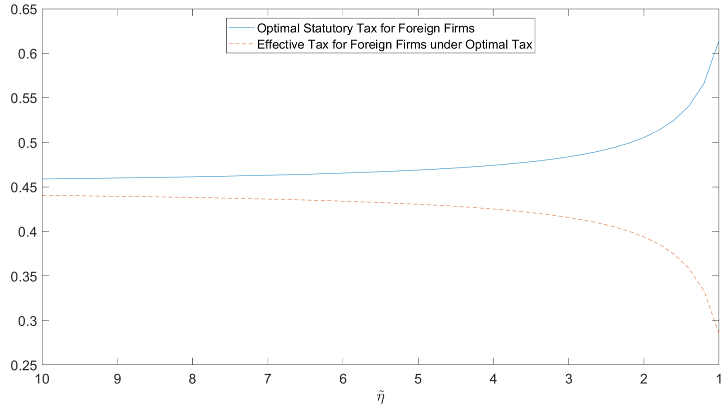



Figure 3: Statutory and Effective Optimal Corporate Taxes on Foreign Firms

### 3.4 Welfare Losses from Corporate Tax Competition

In Section 3.2 and 3.3, I have shown that a country can gain from imposing higher corporate taxes on foreign firms than on domestic firms, at the expense of other countries. What would occur if all countries do this simultaneously? In this subsection, I investigate the consequences of a non-cooperative tax game. I again turn to the two-country world discussed in Section 3.2.[24] Each country decides its corporate tax rates to maximize its welfare, taking the corporate tax rates in the other country as given. I take $w_1^p$ as the numeraire.

Table 1: Nash taxes in the Two-Country World

| | Tax-Free | Nash Tax |
|---|---|---|
| Tax rates | $\tilde{\kappa}_{nn} = \tilde{\kappa}_{in} = 0$ | $\tilde{\kappa}_{nn} = 0.047$, $\tilde{\kappa}_{in} = 0.45$ |
| Real income | 1.089 | 1.07 |
| MP share | 50% | 36.4% |
| $w_i^e$ | 0.61 | 0.57 |
| $L_i^e$ | 0.328 | 0.293 |
| Tax income | 0 | 0.0544 |
| Price | 0.985 | 1.04 |

(Note: $\gamma_{i\ell} = \tau_{\ell n} = 1$ for all $(i, \ell, n)$, $A_i = T_i = \bar{L}_i = 1$ for $i = 1, 2$, $\theta = \sigma = 4$, $\epsilon = 6$, and $\tilde{\eta} = \infty$.)

Table 1 compares the tax-free equilibrium with the Nash equilibrium. When two countries manipulate corporate taxes simultaneously, they impose much higher tax rates on foreign firms than on domestic firms, which reduces MP dramatically. The welfare losses from this tax competition mainly come from two sources. First, it reduces firm entry in both countries and thereby the wage incomes of innovation workers. Second, the decline of firm entry

[24]Notably, I set $N = 2$, $\gamma_{i\ell} = \tau_{\ell n} = 1$ for all $(i, \ell, n)$, $A_i = T_i = \bar{L}_i = 1$ for $i = 1, 2$, $\theta = \sigma = 4$, $\epsilon = 6$, and $\tilde{\eta} = \infty$.

increases the price indices in both countries. The increase in tax revenues cannot fully offset these losses. Consequently, comparing to the world without corporate taxes, both countries lose from this tax competition.

# 4 Estimation

In this section, I bring my model to the world economy in 2007 with 28 major countries.[25] Equilibrium in relative changes suggests that the parameters needed for quantitative assessment include elasticities $(\theta, \epsilon, \rho, \mu, \sigma)$, pre-tax trilateral trade flows $(X_{i\ell n})$, corporate income tax rates $(\tilde{\kappa}_{i\ell})$, and profit-shifting cost $\tilde{\eta}$. My empirical implementation is arranged as the following. First, I calibrate $(\theta, \mu, \sigma)$ from the literature. Second, I estimate $\frac{\epsilon}{1-\rho}$ and $\tilde{\eta}$ using statutory bilateral tax rates $(\tilde{\kappa}_{i\ell})$ and MP flows. Third, I calibrate $\rho$ and impute $(X_{i\ell n})$.

## 4.1 Parameters from Existing Literature

There are several parameters in my model that are commonly used in the literature and I directly take the numbers there. Table 2 summarizes the parameters calibrated from the literature. I set the elasticity of substitution, $\sigma$, at 4 (ARRY (2018)), the dispersion of core productivity, $\theta$, at 4 (ARRY (2018)), and the dispersion of labor units, $\mu$, at 3 (Hsieh et al. (2016)).

Table 2: Calibration of $(\sigma, \theta, \mu)$

| Parameter | Source |
|---|---|
| $\sigma = 4$ | Profit share. ARRY (2018) |
| $\theta = 4$ | "Unrestricted" gravity equation. ARRY (2018) |
| $\mu = 3$ | Labor mobility w.r.t. real income. Hsieh et al. (2016) |

## 4.2 Data

I use a variety of data sources to measure corporate tax rates in country $\ell$ on firms originated from country $i$, $\tilde{\kappa}_{i\ell}$. Ideally, I want to observe the tax rates that actually affect firms' location choices.[26] It is well-documented that the statutory corporate tax rates depart

[25] These economies are Australia, Austria, Belgium, Brazil, Canada, China, Germany, Spain, Finland, France, the UK, Greece, Hungary, Indonesia, India, Ireland, Italy, Japan, Korea, Mexico, the Netherlands, Poland, Portugal, Russia, Sweden, Turkey, Taiwan, and the US.

[26] Based on the discussion in Section 2.3, $\tilde{\kappa}_{i\ell}$ should be the effective corporate tax rates firms face in the absence of profit shifting.

considerably from the effective corporate tax rates due to various reasons *other than profit shifting* (e.g. deductions, exemptions, credits, and preferential rates). Therefore, I use data from PwC Global Effective Tax Rates (2011) to measure the effective local corporate tax rates in 28 countries in 2007.[27] For NRDW tax rates, there are no estimates on the effective tax rates. Therefore, I use the statutory NRDW tax rates summarized in Huizinga, Voget, and Wagner (2014). $\tilde{\kappa}_{i\ell}$ is then computed by Equation (5) for all $(i, \ell)$. Appendix B.1 provides details of the data sources.

To impute pre-tax trilateral trade flows ($X_{i\ell n}$), it requires bilateral trade and MP flows across 28 countries. Bilateral trade flows in 2007 (including domestic production values) come from World Input-Output Database. Bilateral MP sales in 2007 are imputed from bilateral FDI stocks in the UNCTAD database. The data construction is detailed in Appendix B.1.

## 4.3 Empirical Evidence

Before structurally estimating the model's key parameters, $\epsilon$ and $\rho$, I provide reduced-form evidence for the impacts of corporate tax rates on MP sales. Inspired by Huizinga and Voget (2009), I estimate the following non-structural gravity equation:

$$\log \tilde{X}_{i\ell}^{MP} = \beta_1 \log (1 - \tilde{\kappa}_{i\ell}) + \text{grav}_{i\ell}\beta_2 + fe_i + fe_\ell + u_{i\ell}, \tag{29}$$

where $\tilde{X}_{i\ell}^{MP}$ is the bilateral MP sales across 28 countries in 2007, $\tilde{\kappa}_{i\ell}$ is the bilateral corporate tax rates discussed in Section 4.2, $\text{grav}_{i\ell}$ includes gravity variables such as distance dummies, contiguity, common language, and common legal origin, and $fe_i$ and $fe_\ell$ are, respectively, source-country and host-country fixed effects.

Equation (29) is non-structural because it does not take profit shifting into account. However, it still sheds light on the impacts of corporate taxation on MP. I run this regression in both the full sample and the sample without domestic production (excluding the observations with $i = \ell$). The model in Section 2 predicts that (i) $\beta_1$ is positive in both regressions since high corporate tax rates impede MP entry, and (ii) the regression in the sample without domestic production would yield a larger $\beta_1$, since foreign affiliates are more responsive to corporate taxes than domestic plants.

The results in Table 3 confirm the model's predictions. $\beta_1$ is significant and positive in both regressions, suggesting that low corporate tax rates do induce MP entry. Notice that

[27] For countries that are not covered by or have only few firms in PwC Global Effective Tax Rates (2011), I use data from KPMG's Corporate and Indirect Tax Rate Survey.

all source-country-specific factors such as technologies and all host-country-specific factors such as wages are controlled by fixed effects. Moreover, $\beta_1$ is larger in the regression without domestic production than in the regression with the full sample. This confirms the idea in Equation (13) that foreign affiliates are more responsive to changes in corporate tax rates than domestic plants.

Table 3: Bilateral MP sales and corporate tax rates

| Dependent Variable: Observed bilateral MP sales (in log) | | |
|---|---|---|
| | All | $i \neq \ell$ |
| $\log\left(1-\tilde{\kappa}_{i\ell}\right)$ | 1.770* | 2.085*** |
| | (.99) | (.47) |
| $\mathbf{1}\left\{\text{Dist} \in [1000 \text{ km}, 11000 \text{ km}]\right\}$ | -2.229*** | -.894*** |
| | (.26) | (.11) |
| $\mathbf{1}\left\{\text{Dist} > 11000 \text{ km}\right\}$ | -3.107*** | -1.401*** |
| | (.34) | (.15) |
| Contiguity | -.560** | .759*** |
| | (.26) | (.14) |
| Common language | 1.911*** | .570*** |
| | (.28) | (.18) |
| Common legal origin | .692*** | .483*** |
| | (.12) | (.089) |
| Source/host fixed effects | ✓ | ✓ |
| $R^2$ | .980 | .991 |
| # Obs. | 784 | 756 |

For robustness, I estimate Equation (29) using alternative data sources. First, I regress the bilateral MP sales in 2001 from Ramondo et al. (2015) on the statutory corporate tax rates in 2001 from Huizinga, Voget, and Wagner (2014). Second, I regress the bilateral MP sales in 2007 constructed in Section B.1 on the statutory corporate tax rates in 2007 from KPMG Corporate and Indirect Tax Rate Survey (2008). The results are presented in Table B.2 of Appendix B.2. The coefficient of bilateral corporate tax rates remain largely unchanged in these robustness tests.

## 4.4 Estimating $\frac{\epsilon}{1-\rho}$

The dispersion of productivities across foreign production sites, $\frac{\epsilon}{1-\rho}$, characterizes to what extent changes in corporate tax rates affect MNEs' production sites abroad. A large $\frac{\epsilon}{1-\rho}$ implies that a small change in trade or MP cost can lead to substantial production relocation of foreign MNEs. As shown in Section 3, the welfare impacts of corporate taxes are sensitive with respect to $\frac{\epsilon}{1-\rho}$.

In this subsection, I estimate $\frac{\epsilon}{1-\rho}$ from Equation (13). Specifically, for $i \neq \ell$, I have

$$\log X_{i\ell}^{MP} = -\left[\frac{\epsilon}{1-\rho} - (\sigma - 1)\right] \log\left(\kappa_{i\ell}\right) - \frac{\epsilon}{1-\rho} \log \gamma_{i\ell} + \delta_i^o + \delta_\ell^d, \tag{30}$$

where $X_{i\ell}^{MP} := \sum_{n=1}^{N} X_{i\ell n}$ is the "true" bilateral MP flows without profit shifting, $\delta_i^o$ is the source-country fixed effect and $\delta_\ell^d$ is the host-country fixed effect. Following ARRY (2018), I parameterize $\gamma_{i\ell}$ in terms of gravity variables:

$$\log\left(\gamma_{i\ell}\right) = \text{grav}_{i\ell} \delta^{\text{grav}} + v_{i\ell}^{\gamma}. \tag{31}$$

If there is no profit shifting, Equation (30) would be equivalent to Equation (29) for $i \neq \ell$ and $\frac{\epsilon}{1-\rho}$ can be calculated directly from the estimates on $\beta_1$ in Equation (29). However, the firms' profit shifting invalidates this estimation strategy in two dimensions. First, the observed bilateral MP flows, $\left(\tilde{X}_{i\ell}^{MP}\right)$, would deviate from the "true" bilateral MP flows due to profit shifting. Second, the bilateral corporate tax rates $(\tilde{\kappa}_{i\ell})$ would deviate from the effective corporate tax rates under profit shifting.

The model implies that the observed bilateral MP flows are given by

$$\tilde{X}_{i\ell}^{MP} = X_{i\ell}^{MP} - \underbrace{\sum_k \frac{1}{\sigma} \max\left\{\frac{\tilde{\kappa}_{i\ell} - \tilde{\kappa}_{ik}}{\tilde{\eta}/\lambda_{ik}^{MP}}, 0\right\} X_{i\ell}^{MP}}_{\text{Profts shifting out}} + \underbrace{\sum_k \frac{1}{\sigma} \max\left\{\frac{\tilde{\kappa}_{ik} - \tilde{\kappa}_{i\ell}}{\tilde{\eta}/\lambda_{i\ell}^{MP}}, 0\right\} X_{ik}^{MP}}_{\text{Profits shifting in}}. \tag{32}$$

Given $\tilde{\eta}$, the "true" bilateral MP flows can be solved by iterating Equation (32).[28] I then choose $\tilde{\eta}$ to match magnitude of the shifted profits of the U.S. multinationals:

$$\sum_k \max\left\{\frac{\tilde{\kappa}_{\text{USA,USA}} - \tilde{\kappa}_{\text{USA},k}}{\tilde{\eta}/\lambda_{\text{USA},k}^{MP}}, 0\right\} = 0.01 \tag{33}$$

Bruner et al. (2018) suggests that the U.S. multinationals shift about 3% of their profits earned in the U.S. to their foreign affiliates in 2014. Notably, I include only 28 countries in the empirical estimation. In these 28 countries, the Netherlands and Ireland are among the largest destinations for the U.S. multinationals to shift their profits (Guvenen et al., 2018), which account for about one third of the shifted profits. Therefore, I choose $\tilde{\eta}$ so that the U.S. multinationals shift 1% of their profits earned in the U.S. to their foreign affiliates in the model. This delivers an estimate of $\tilde{\eta} = 0.42$.

[28] See Section B.3 for the details of this iteration.

Armed by "true" bilateral MP flows, $X_{i\ell}^{MP}$, and the parameter for profit-shifting cost, $\tilde{\eta}$, I compute $\kappa_{i\ell}$ by Equation (10) and estimate Equation (30) by fixed-effect regression.

The result in Table 4 suggests that $-\frac{\epsilon}{1-\rho} + (\sigma - 1) = -4.692$, which implies that $\frac{\epsilon}{1-\rho} = 7.692$. This estimate is in line with the coefficient estimated by the "restricted" gravity equation in ARRY (2018). Using the multinational sales of the U.S. MNEs and tariff data, they estimate the elasticity of firm production entry with respect to iceberg MP costs as $-8.4$.[29]

Table 4: The Estimate on $\frac{\epsilon}{1-\rho}$

| Dependent Variable: "True" bilateral MP sales (in log, $i \neq \ell$) | |
|---|---|
| $\log \kappa_{i\ell}$ | -4.692* |
| | (2.84) |
| $\mathbf{1}\{\text{Dist} \in [1000 \text{ km}, 11000 \text{ km}]\}$ | -.924*** |
| | (.11) |
| $\mathbf{1}\{\text{Dist} > 11000 \text{ km}\}$ | -1.434*** |
| | (.14) |
| Contiguity | .734** |
| | (.14) |
| Common language | .573*** |
| | (.17) |
| Common legal origin | .512*** |
| | (.09) |
| Source/host fixed effects | ✓ |
| $R^2$ | .94 |
| # Obs. | 756 |

## 4.5 Calibrating $\rho$ and Imputing $(X_{i\ell n})$

There is no clear identification for $\rho$ from the aggregate data of MP flows and corporate tax rates. Then reason is that when running the regression in Equation (30) with the full sample, the coefficient of $\log \kappa_{i\ell}$ is non-structural.[30] However, the reduced-form results in Table 3 do imply that $\rho > 0$. Utilizing these reduced-form results, I calibrate $\rho$ to match the following moment:

$$\frac{\frac{\epsilon}{1-\rho} - (\sigma - 1)}{\epsilon - (\sigma - 1)} = \frac{2.085}{1.770} = 1.18. \tag{34}$$

Notice that 2.085 is the estimated coefficient of $\log(1 - \tilde{\kappa}_{i\ell})$ for $i \neq \ell$ in Equation (29) and 1.77 is the estimated coefficient of $\log(1 - \tilde{\kappa}_{i\ell})$ for all pairs. This leads to $\epsilon = 6.98$ and

[29] See ARRY (2018) for details. $-8.4$ is their estimate using Poisson PML estimator. OLS leads to the estimate as $-10.9$.

[30] Based on Equation (13), this coefficient should lie between $-\left[\frac{\epsilon}{1-\rho} - (\sigma - 1)\right]$ and $-[\epsilon - (\sigma - 1)]$.

$\rho = 0.093$. To understand the role of $\rho$, I test the sensitivity of my quantitative results under alternative values of $\rho$. The sensitivity tests are presented in Appendix B.6.

My quantification requires the data on "true" trilateral sales flows $\{X_{i\ell n}\}$. Unlike bilateral trade and MP flows, $\{X_{i\ell n}\}$ are not observed in the data. Following the strategy developed ARRY (2018), I impute $\{X_{i\ell n}\}$ from bilateral trade and MP data, given the parameters $(\epsilon, \rho, \theta, \sigma, \tilde{\eta})$. In particular, I denote $\tilde{T}_{i\ell} := (M_i T_i)^{-\frac{1}{\theta}} A_\ell^{-\frac{1-\rho}{\epsilon}} \gamma_{i\ell} w_\ell$ for $i \neq \ell$ and $\tilde{T}_{ii} := (M_i T_i)^{-\frac{1}{\theta}} A_i^{-\frac{1}{\epsilon}} w_i$ and then express $\{X_{i\ell n}\}$ in terms of $(\tilde{T}_{i\ell}, \tau_{\ell n}, \kappa_{i\ell})$. Then I compute $(\tilde{T}_{i\ell}, \tau_{\ell n})$ by matching the model-implied bilateral trade and MP flows to their data counterparts. The algebra is presented in Appendix B.4.

# 5 Quantifying the Effects of Corporate Taxation

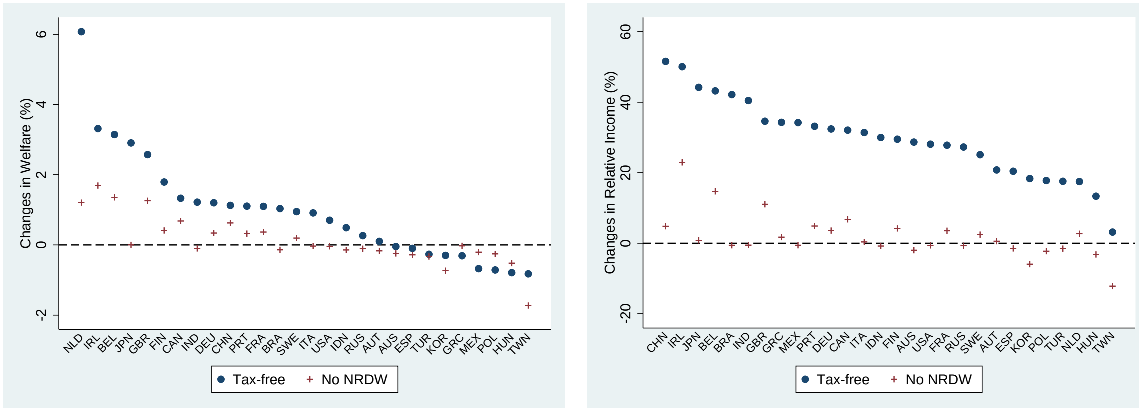
In this section, I investigate the welfare effects of corporate taxes to demonstrate the usefulness of my model in understanding corporate tax reforms in reality. As discussed in Section 2, the welfare of country $i$ is measured by the real income in country $i$. In addition to welfare, I also examine the impacts of corporate taxes on the wage share of innovation workers (henceforth *innovation share*):

$$r_i := \frac{w_i^e L_i^e}{w_i^e L_i^e + w_i^p L_i^p}. \tag{35}$$

This measure helps us to understand whether a country is specialized in innovation or production. It also depicts the income distribution between innovation and production workers, which is at the center of many policy debates.

## 5.1 Elimination of Corporate Taxes

I first examine the welfare and distributional effects of eliminating corporate taxes. Figure 4 illustrates the consequences of eliminating corporate taxes. I consider two scenarios (i) eliminating all corporate taxes, and (ii) eliminating NRDW taxes so that firms producing in the same country face the same corporate tax rate. Panel (a) of Figure 4 shows that most countries gain from the elimination of all corporate taxes. This is mainly due to the increase in firm entry. However, more than half of the countries lose from eliminating NRDW taxes due to firm relocation and the decline in tax revenues. Panel (b) shows that the elimination of all corporate taxes increases the innovation share in all countries, whereas the elimination of NRDW taxes has ambiguous effects on innovation share.

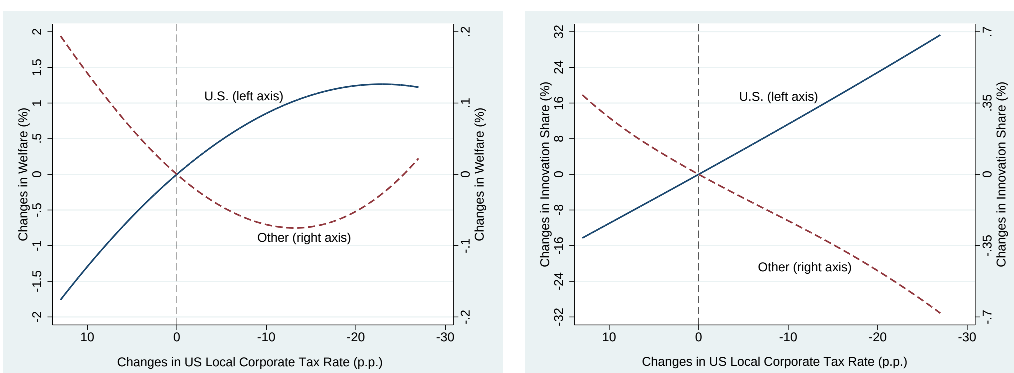



(a) Welfare (b) Innovation Share

Figure 4: Consequences of Eliminating Corporate Taxes
(Notes: Innovation share refers to the wage share of innovation workers expressed by Equation (35).)

## 5.2 Corporate Tax Reform in the U.S.

In this subsection, I quantify the welfare effects of the U.S. corporate tax reform. The United States is the largest FDI sender and one of the largest FDI receivers in the world. Its corporate tax policies thus have major impacts on the world economy. Motivated by the Tax Cuts and Jobs Act of 2017, I consider the reduction in the U.S. local corporate tax rate, keeping its NRDW tax rates unchanged.




(a) Welfare (b) Innovation Share

Figure 5: The Welfare and Distributional Effects of the U.S. Corporate Tax Reform
(Notes: Innovation share refers to the wage share of innovation workers expressed by Equation (35). The effect for other countries are an average of the effects for countries other than the U.S. weighted by their pre-change absorptions. The NRDW tax rates are fixed at their factual levels.)

Panel (a) of Figure 5 shows that the reduction in the U.S. local corporate tax rate would increase the real income in the U.S. This is mainly due to the home market effects of innovation discussed in Proposition 3. Decreasing the U.S. local corporate tax rate by

13 percentage points would increase the U.S. real income by about 1%. In the meanwhile, the reduction in the U.S. local corporate tax rate would decrease the average real income in other countries. This is mainly due to (i) firm relocation to the U.S. and (ii) the decline in profits shifted from the U.S. to other countries.

Panel (b) of Figure 5 suggests that in the U.S. innovation workers gain more from corporate tax reduction than production workers. This makes the U.S. further specialize in innovation. The opposite occurs in other countries.

### 5.3 Corporate Tax Reform in the U.K. after Brexit

In this subsection, I investigate the impacts of the (possible) corporate tax reduction in the U.K. after Brexit. Brexit will inevitably increase trade and MP costs between the U.K. and the European Union (EU). There are hot debates about through what policies the U.K. could at least partially offset the negative effects led by Brexit. A candidate of these policies is to reduce the U.K. corporate tax rate.

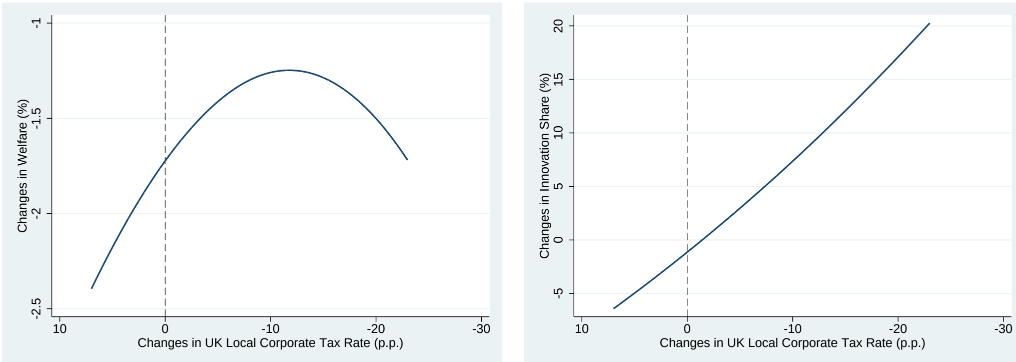
I conduct the counterfactual experiment by two steps. First, following ARRY (2018), I increase trade and MP costs between the U.K. and the EU countries in my sample by 5%. Figure 6 suggests that increasing barriers to trade and MP with the EU would reduce real income in the U.K. by 1.7%.

Second, I changes the local corporate tax rate in the U.K. after Brexit. Figure 6 shows that if the U.K. reduces its local corporate tax rate by 12 percentage points, its welfare loss from Brexit will decrease from 1.7% to 1.2%. The reduction of the U.K. corporate tax rate would induce firm entry into the U.K., partially offsetting the relocation of firms from the U.K. to the EU led by Brexit. As a result, this tax cut would compensate about one third of the U.K. welfare loss from Brexit.

However, the benefits of corporate tax cut do not distribute equally between innovation and production workers. Panel (b) of Figure 6 suggests that (i) Brexit decreases the innovation share in the U.K. by relocating firms from the U.K. to the EU, and (ii) if the U.K. wants to mitigate its welfare loss from Brexit by lowering its local corporate tax rate, its innovation share will increase dramatically.

## 6 Tax Wars and Tax Talks

In this section, I use the calibrated model to provide a quantitative analysis of non-cooperative and cooperative tax policy in the presence of MP. I first quantify the govern-




(a) Welfare in the U.K.

(b) Innovation Share in the U.K.

Figure 6: Corporate Tax Reform in the U.K. after Brexit

(Notes: Innovation share refers to the wage share of innovation workers expressed by Equation (35). Brexit refers to 5 percent increase in trade and MP costs between U.K. and the EU countries in my sample. Changes in welfare and innovation share are relative to their levels before Brexit and corporate tax reform.)

ments' incentives to manipulate corporate taxation by considering the unilaterally optimal taxes in each country. Then I solve for the Nash corporate taxes to understand the consequences of international tax competition. Finally, I compute the cooperative tax rates to quantify welfare gains from international tax cooperation. Notably, fully non-cooperative tax competition and fully cooperative tax negotiation are both extremes that are useful to understanding international tax conflicts and treaties in reality.

## 6.1 Unilaterally Optimal Corporate Taxes

In this subsection, I compute the unilaterally optimal corporate taxes of all 28 countries, assuming each time that all other countries do not deviate from their factual tax rates. The goal is to understand countries' incentives for unilateral policy intervention which are behind the best response equilibrium analyzed in Section 6.2. I compute optimal taxes using the Su and Judd (2012) method of mathematical programming with equilibrium constraints.[31] To find global maxima, I randomize the initial guesses and the algorithm always converges to the same set of solutions.

Table 5 summarizes the optimal taxes of all 28 countries. To maximize its own welfare, each country tends to tax foreign firms to subsidize its domestic firms (See Column (1) and (3) of Table 5). This is consistent with the home market effect in innovation and the terms-of-trade effect shown in Proposition 3. Notably, the home market effect in innovation is so strong that for most countries in my sample the optimal local corporate tax rates are

[31]The details of this constrained optimization problem is presented in Appendix B.5.

Table 5: Unilaterally Optimal Corporate Taxes

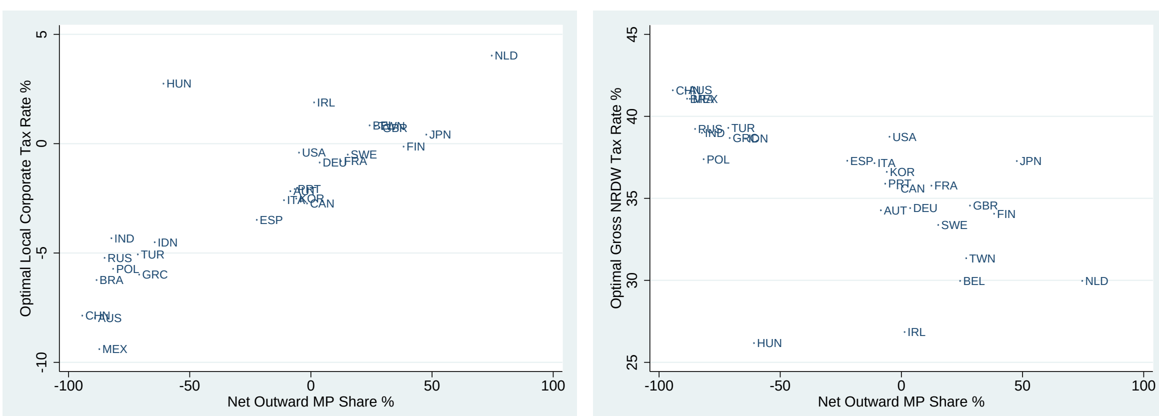
| | Tax Rate for Domestic Firms (%) | | Tax Rate for Foreign Firms (%) | | Changes in Welfare (Δ%) | |
|---|---|---|---|---|---|---|
| | Optimal | Factual | Optimal | Factual | Own | Other |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| AUS | -7.96 | 27.10 | 33.65 | 35.58 | 1.72 | -0.03 |
| AUT | -2.17 | 19.70 | 32.10 | 28.57 | 1.13 | -0.01 |
| BEL | 0.84 | 33.99 | 30.80 | 34.19 | 2.25 | -0.01 |
| BRA | -6.23 | 34.00 | 34.84 | 34.00 | 2.36 | -0.03 |
| CAN | -2.73 | 21.60 | 32.87 | 35.77 | 1.29 | -0.02 |
| CHN | -7.86 | 33.00 | 33.73 | 20.00 | 3.26 | -0.39 |
| DEU | -0.86 | 27.90 | 33.54 | 36.87 | 1.78 | -0.08 |
| ESP | -3.48 | 21.80 | 33.81 | 34.20 | 1.23 | -0.03 |
| FIN | -0.13 | 26.00 | 33.93 | 30.18 | 1.69 | -0.01 |
| FRA | -0.80 | 23.10 | 34.98 | 33.40 | 1.32 | -0.05 |
| GBR | 0.73 | 23.60 | 35.29 | 30.22 | 1.24 | -0.04 |
| GRC | -5.99 | 25.20 | 32.69 | 29.28 | 1.75 | -0.01 |
| HUN | 2.75 | 13.70 | 28.92 | 23.92 | 0.77 | -0.00 |
| IDN | -4.51 | 28.10 | 34.13 | 28.10 | 1.66 | -0.01 |
| IND | -4.32 | 33.99 | 34.67 | 33.99 | 2.14 | -0.02 |
| IRL | 1.89 | 12.50 | 28.74 | 23.05 | 1.26 | -0.01 |
| ITA | -2.58 | 29.10 | 34.56 | 38.17 | 1.82 | -0.05 |
| JPN | 0.42 | 39.80 | 37.69 | 43.21 | 3.11 | -0.13 |
| KOR | -2.51 | 24.30 | 34.11 | 32.59 | 1.35 | -0.03 |
| MEX | -9.39 | 27.20 | 31.67 | 30.45 | 1.99 | -0.04 |
| NLD | 4.03 | 18.80 | 34.00 | 28.50 | 0.45 | -0.01 |
| POL | -5.72 | 19.00 | 31.66 | 26.63 | 1.26 | -0.02 |
| PRT | -2.07 | 26.50 | 33.82 | 31.19 | 1.86 | -0.01 |
| RUS | -5.22 | 26.00 | 34.01 | 26.00 | 1.49 | -0.03 |
| SWE | -0.50 | 22.00 | 32.88 | 29.44 | 1.14 | -0.01 |
| TUR | -5.06 | 20.00 | 34.23 | 30.13 | 0.90 | -0.01 |
| TWN | 0.82 | 14.40 | 32.17 | 14.40 | 1.34 | -0.02 |
| USA | -0.41 | 27.70 | 38.35 | 38.51 | 1.61 | -0.34 |
| Average | -2.47 | 25 | 33.5 | 30.7 | 1.6 | -0.05 |

(Note: the tax rate for foreign firms are an average of the tax rates across source countries weighted by their pre-change absorptions. Similar average is computed to measure the welfare effect for countries other than the implementing country. The last row presents simple averages across all countries.)

negative. In reality, countries do not directly subsidize their domestic firms via negative corporate taxes (see Column (2) of Table 5). This may reflect the fact that governments tend to subsidize domestic firms via channels other than negative corporate taxes. In recent policy debates about industrial subsidies, most of the subsidies target on domestic firms. If we take all industrial subsidies into account, the de facto structure of taxes/subsidies on domestic and foreign firms may be close to the optimal taxes shown in Table 5.

For most of the countries, the optimal corporate tax rates for foreign firms are close to their factual levels, which means that the optimal gross NRDW tax rates are much higher than their factual levels.[32] In reality, countries do not decide their corporate tax rates unilaterally. Instead, they sign bilateral tax or investment treaties to coordinate their corporate taxes and avoid prohibitive NRDW taxes.

Figure 7 connects the optimal corporate tax rates with countries' specialization in innovation or production. As discussed in Section 2, a country specializes in innovation if it has large net outward MP. Figure 7 shows that the optimal local corporate tax rate is increasing with the net outward MP share, whereas the optimal gross NRDW tax rate is decreasing with the net outward MP share. These results confirm the insights in Section 3.3: with stronger comparative advantage in production, a country gains more from protecting its domestic firms because in this case the varieties created by domestic firms are more likely to be produced domestically.




(a) Optimal Local Tax

(b) Optimal Gross NRDW Tax

Figure 7: Optimal Taxes and the Specialization in Innovation/Production

(Note: Net outward MP share is defined as the difference between outward MP and inward MP divided by their sum.)

[32]This result is similar to the finding in Ossa (2014) in which the unilaterally optimal tariffs are much higher than the factual tariffs.

I then connect the optimal tax rates with openness to MP, controlling for countries' specialization in innovation and production. Table 6 shows that the optimal gross NRDW tax rate is increasing with the own production share. Consistent with the discussion in Section 3.3, a country has stronger incentives to protect its domestic firms as these firms become more important to local workers and consumers.

Table 6: Optimal Taxes, Openness, and Specialization in Innovation/Production

| | Local Tax | Gross NRDW Tax |
|---|---|---|
| Own Production Share | -0.0371 | 0.135*** |
| | (0.033) | (0.042) |
| Net Outward MP share | 0.0567*** | -0.0491*** |
| | (0.0071) | (0.0097) |
| Constant | 1.218 | 26.28*** |
| | (2.21) | (2.88) |
| $R^2$ | 0.736 | 0.655 |
| # Obs. | 28 | 28 |

(Note: The dependent variables are the optimal local tax rates and gross NRDW tax rates listed in Table 5. Net outward MP share is defined as the difference between outward MP and inward MP divided by their sum. Own production share is the production value of domestic firms as a share of total production value in the host country.)

Column (5) and (6) of Table 5 elaborates on the welfare effects of the optimal corporate taxes, listing the welfare effects on the tax imposing countries ("own") and the average welfare effects on all other countries ("other"). As can be seen, countries indeed gain at the expense of others. The substantial welfare gains of China and Japan from optimal taxation are due to their highly distorted factual tax rates. The Japanese corporate tax rates are too high for foreign firms, whereas China imposes lower corporate taxes on foreign firms than on domestic firms. These distortions have been partially removed by the recent tax reforms in these two countries.

## 6.2 Tax Competition

The discussion of optimal tariffs assumes that each country manipulates corporate taxes without fear of other countries' retaliation. I now turn to analyze the Nash equilibrium in which countries retaliate optimally. There are increasing concerns about the breakdown of international cooperation in corporate taxation. This exercise provides a useful benchmark to understand what would happen if all of the over 3000 bilateral tax treaties are completely abandoned.[33]

It is computational challenging to solve the Nash equilibrium in a game with 28 players.[34] To address the problem of dimensionality and highlight the policy relevance, I consider tax competition across eight major countries in MP activities:[35] Belgium, Canada, Germany, France, Britain, Ireland, the Netherlands, and the U.S. These countries have been involved into a considerable numbers of tax conflicts.[36]

Figure 8 illustrates the Nash corporate tax rates of the eight countries and the rest of the world. Comparing to the unilaterally optimal tax rates,[37] a country will impose a lower corporate tax rate on its domestic firms and higher tax rates on foreign firms. This is because other countries' retaliation makes firms move back to their source countries, which strengthens each country's incentives for protecting domestic firms. As a result, tax competition would lower local corporate tax rates in all participation countries. This result resembles the race-to-the-bottom tax competition emphasized by the literature.[38]

Similar to what have been discussed in the optimal taxes, Figure 8 shows that the Nash local corporate tax rates are much lower than the factual local tax rates, whereas the Nash gross NRDW tax rates are much higher than their factual levels. On the one hand, it implies that in reality countries do not impose prohibitive NRDW taxes as they will do in tax wars. On the other hand, it reflects the fact that my model does not take all subsidies on domestic firms into account.

Table 7 elaborates on the welfare effects of Nash taxes. Consistent with the illustrative example in Section 3.4, tax competition reduces MP and thereby generates welfare losses in the participation countries. Comparing to the factual equilibrium, five out of eight countries lose from the Nash taxes. The Netherlands experiences the largest loss from tax competition since it is a small open economy that specializes in innovation. In particular, the dramatic

[33]In reality, it is unlikely that some or all existing bilateral tax treaties are completely abandoned. However, major political or institutional changes may affect the effectiveness of these treaties. One recent example is Brexit. It has profound tax implications for British MNEs operating in Europe. See details in the KPMG report via https://home.kpmg.com/uk/en/home/insights/2016/09/impact-of-brexit-on-tax.html.

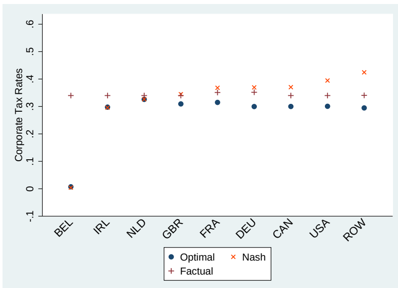
[34]To compute the best response for one country, I need to solve an optimization problem with $6 \times 28 + 28^2 + 28 = 980$ variables and $6 \times 28 + 28^2 = 952$ constraints.

[35]I bundle other economies as the rest of the world

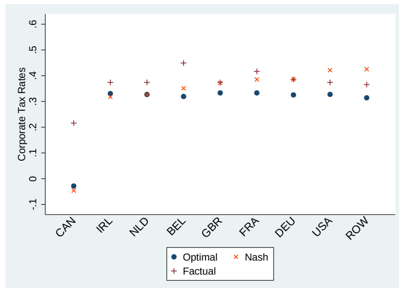
[36]For example, the EU has long complained about the low corporate tax rates in Ireland. Similar conflicts have occurred between the EU and the Netherlands. Moreover, Britain plans to lower its corporate tax rates to cushion hit from Brexit, which may lead to retaliation from the EU. President Trump's corporate tax reform is another potential stimulus for tax wars.

[37]Here Unilaterally optimal tax rates are computed in a world with eight participation countries and the rest of the world.

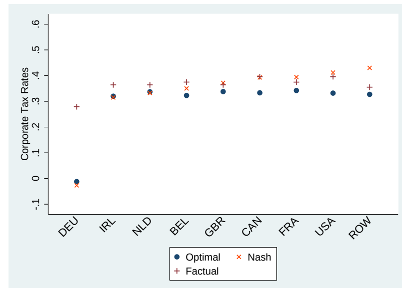
[38]For example, Devereux (2014) finds evidence suggesting that the competition of corporate taxes can lead to tax cuts in participation countries.



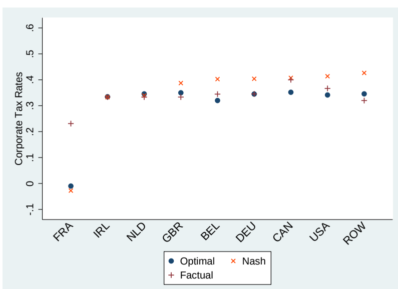

(a) Belgium



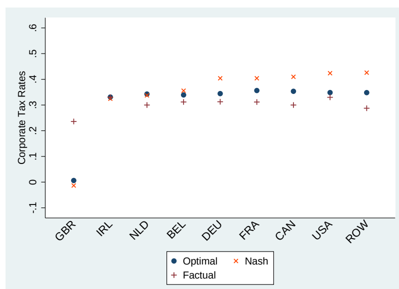

(b) Canada



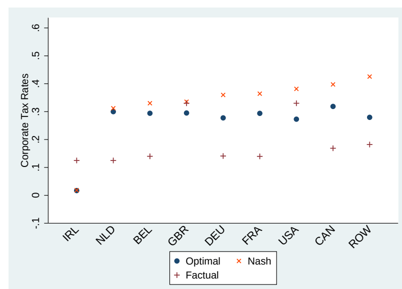

(c) Germany



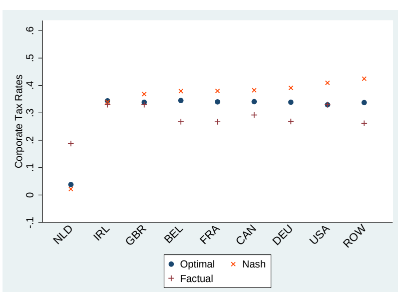

(d) France



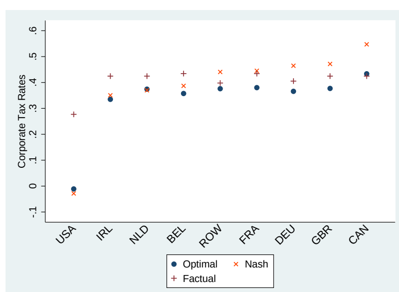

(e) U.K.



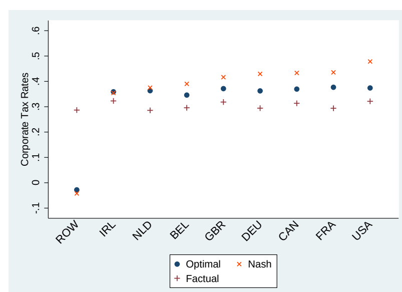

(f) Ireland




(g) The Netherlands




(h) U.S.




(i) ROW

Figure 8: Nash Corporate Taxes

Table 7: The Effects of Nash Corporate Taxes

| | Relative to Factual Equilibrium | | | Relative to Tax-Free Equilibrium | | |
|---|---|---|---|---|---|---|
| Changes in: | Welfare (1) | Innovation Share (2) | MP Share (3) | Welfare (4) | Innovation Share (5) | MP Share (6) |
| Belgium | -0.73 | 20.0 | -11.30 | -3.54 | -14.5 | -10.4 |
| Canada | -0.22 | 7.7 | -0.43 | -1.56 | -18.4 | -3.5 |
| Germany | 0.19 | 25.0 | -5.46 | -1.08 | -5.8 | -6.9 |
| France | -0.44 | 16.1 | -3.32 | -1.40 | -8.0 | -5.9 |
| U.K. | -1.17 | 7.4 | -2.41 | -3.88 | -21.1 | -2.9 |
| Ireland | 0.26 | -8.6 | -2.30 | -2.76 | -38.2 | -2.7 |
| The Netherlands | -6.23 | -19.7 | 3.20 | -12.00 | -32.4 | -0.6 |
| U.S. | 0.83 | 28.7 | -3.39 | -0.07 | -0.5 | -5.5 |
| ROW | 1.65 | 41.8 | -5.17 | 0.96 | 7.0 | -5.1 |

(Notes: The MP share refers to the inward MP as a share of total production value. Changes in welfare and innovation share are measured by percentage changes. Changes in MP share are measured by changes in percentage points.)

increase in NRDW tax rates in all countries substantially reduces the entry of the Dutch MNEs as well as the innovation share in the Netherlands. In contrast, tax competition increases innovation shares in countries such as Germany and the U.S. due to the decline in their local corporate tax rates. Comparing to the tax-free equilibrium, all eight countries lose from the Nash taxes, with dramatic decline in their innovation shares. The rest of the world is an exception: it gains from tax competition even relative to the tax-free equilibrium. This is because the rest of world in this exercise has strong comparative advantage in production. As a result, it gains more from imposing high corporate tax rates on foreign firms than it loses from the increase in the corporate tax rates incurred by the foreign affiliates of its MNEs.

To what extent do profit shifting and MP liberalization matter for the consequences of tax competition? To answer this question, I study in Table 8 tax wars with alternative values of profit shifting costs and MP costs. First, I compute a counterfactual equilibrium in which the profit shifting costs are infinite and then solve the Nash taxes in this counterfactual world. Interestingly, comparing to the baseline case, tax competition in the absence of profit shifting leads to much larger welfare losses for participation countries.[39] Consistent with the illustrative example in Section 3.3, in a non-cooperative tax game countries would impose much higher effective tax rates on foreign firms if these firms cannot shift their profits to low tax countries.[40] A policy implication is that in the absence of international tax cooperation, profit shifting of multinational firms can be welfare-improving since it bounds the capability

[39]Compare Column (1) of Table 8 with Column (1) of Table 7

[40]See Figure B.1 in Appendix B.6 for illustration.

Table 8: Sensitivity Analysis for Nash Corporate Taxes

| | No Profit Shifting | | | MP Liberalization | | |
|---|---|---|---|---|---|---|
| Changes in: | Welfare | Innovation Share | MP Share | Welfare | Innovation Share | MP Share |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Belgium | -4.51 | 2.09 | -19.17 | -1.49 | 13.10 | -11.24 |
| Canada | -1.07 | -6.33 | -7.57 | -3.41 | -39.81 | 12.73 |
| Germany | -1.88 | 10.99 | -12.34 | -0.26 | 17.85 | -5.30 |
| France | -2.06 | 1.83 | -10.20 | -0.79 | 10.00 | -3.02 |
| U.K. | -3.23 | -12.24 | -8.69 | -1.53 | 0.82 | -1.92 |
| Ireland | -1.09 | -46.51 | -2.23 | -0.22 | -7.95 | -2.06 |
| The Netherlands | -12.2 | -47.12 | 0.95 | -7.22 | -19.17 | 2.67 |
| U.S. | -0.81 | 17.98 | -8.71 | 0.53 | 26.06 | -4.73 |
| ROW | 1.50 | 37.76 | -9.50 | 1.95 | 48.57 | -7.96 |

(Notes: All changes are relative to the factual equilibrium. MP liberalization refers to a 10 percent decrease in $\gamma_{i\ell}$ for all $i \neq \ell$. The MP share refers to the inward MP as a share of total production value. Changes in welfare and innovation share are measured by percentage changes. Changes in MP share are measured by changes in percentage points. The details of Nash taxes under alternative parameter values can be seen in Appendix B.6.)

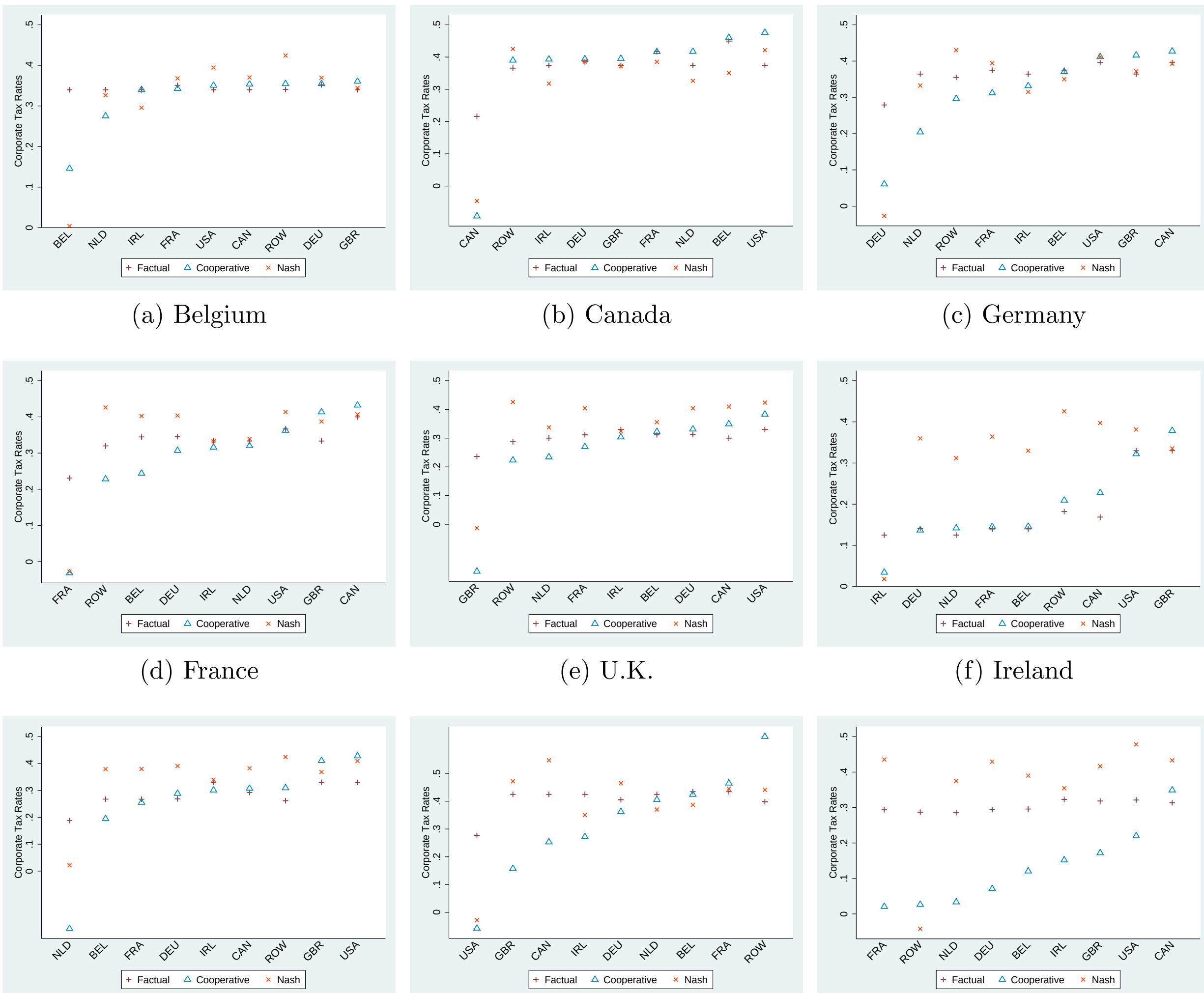
of each country to gain at the expense of others.

Second, I consider tax competition in the world under MP liberalization. I compute a counterfactual equilibrium in which all MP costs are reduced by 10% from their factual level and solve the Nash taxes in this counterfactual world. Table 8 suggests that the efficiency loss created by tax competition is magnified under MP liberalization. Intuitively, MP liberalization signifies foreign firms to workers and consumers in the host country. Therefore, the distorted tax structure that favors domestic firms by imposing high taxes on foreign firms would lead to larger welfare losses.

## 6.3 Tax Talks

Substantial welfare losses from tax competition create incentives for international tax coordination and cooperation. International tax treaties that aim to harmonize corporate taxes across countries and reduce international double taxation have been increasingly important in recent years. I now turn to an analysis of international tax cooperation by characterizing the consequences of tax negotiation among eight countries involved in the tax competition above. Following the specification of trade talks in Ossa (2014), I solve $\max_{(\kappa_{i\ell})} \hat{W}_1$ s.t. $\hat{W}_i = \hat{W}_1 \; \forall i$ starting at factual taxes, quantifying the scope for future mutually beneficial tax cooperation.

Figure 9 compares the cooperative corporate tax rates with the factual taxes and Nash taxes. In a fully efficient tax negotiation, countries lower their corporate tax rates for do-




(a) Belgium (b) Canada (c) Germany

(d) France (e) U.K. (f) Ireland

(g) The Netherlands (h) U.S. (i) ROW

Figure 9: Cooperative Corporate Taxes

mestic *and* foreign firms. This global tax cut boosts the worldwide firm entry and benefits all countries due to the non-rivalry of technologies within the firm.

Figure 9 also shows that in most countries the factual corporate tax rates on foreign firms are closer to the cooperative tax rates than the Nash tax rates. This result suggests that in reality countries are more likely to be in tax cooperation than tax wars. In practice, huge efforts have been made to reduce NRDW rates and harmonize corporate tax rates across countries. A recent example is the re-launch of the Common Consolidated Corporate Tax Base (CCCTB) for EU members.

Table 9: The Effects of Cooperative Corporate Taxes

| | Relative to Factual Equilibrium | | | Relative to Tax-Free Equilibrium | | |
|---|---|---|---|---|---|---|
| Changes in: | Welfare (1) | Innovation Share (2) | MP Share (3) | Welfare (4) | Innovation Share (5) | MP Share (6) |
| Belgium | 0.98 | 7.7 | -1.26 | -1.87 | -23.2 | -0.41 |
| Canada | 0.98 | 22.9 | -1.77 | -0.37 | -6.8 | -4.83 |
| Germany | 0.98 | 15.6 | -0.27 | -0.29 | -12.8 | -1.70 |
| France | 0.98 | 24.0 | -2.19 | 0.00 | -1.7 | -4.73 |
| U.K. | 0.98 | 38.7 | -5.96 | -1.78 | 1.9 | -6.42 |
| Ireland | 0.98 | -7.7 | 1.01 | -2.06 | -37.6 | 0.62 |
| The Netherlands | 0.98 | 14.8 | -4.58 | -5.22 | -3.3 | -8.40 |
| U.S. | 0.98 | 31.8 | -1.75 | 0.08 | 1.9 | -3.85 |
| ROW | 0.98 | 28.1 | -0.83 | 0.29 | -3.2 | -0.76 |

(Notes: The MP share refers to the inward MP as a share of total production value. Changes in welfare and innovation share are measured by percentage changes. Changes in MP share are measured by changes in percentage points.)

Table 9 reports the effects of negotiating from factual to cooperative taxes. As can been seen, cooperative tax rates increase welfare by 0.98% in each participation country. The worldwide decline in corporate taxes led by tax cooperation boosts innovation in most participation countries, as suggested by Column (2) of Table 9. Moreover, the welfare under cooperative taxes in countries such as France, Germany, and the U.S. is close to their welfare under tax-free equilibrium (see column (1) and (4) of Table 9). A fully efficient tax negotiation tends to push the world economy towards the tax-free equilibrium by partially correct distortions led by tax competition.

Then I investigate the implications of profit shifting and MP liberalization for international corporate tax coordination. First, I solve the cooperative tax rates in the world without profit shifting. Column (1) of Table 10 shows that without profit shifting countries can gain more from tax cooperation. Intuitively, profit shifting bounds the differences of corporate tax rates across countries and thus limits the scope for tax cooperation.[41] This

[41]Figure B.2 in Appendix B.6 illustrates cooperative tax rates with and without profit shifting. It shows

result suggests that reducing MNEs' profit shifting is essential for countries to gain from international tax cooperation.

Second, I solve cooperative taxes under MP liberalization. I compute a counterfactual equilibrium in which all MP costs are reduced by 10% from their factual level and then solve the cooperative taxes in this counterfactual world. Column (4) of Table 9 reports the welfare effects of cooperative taxes under MP liberalization. It suggests that the benefits of tax cooperation are magnified under MP liberalization. Intuitively, starting at lower MP costs, corporate taxes that impede MP lead to larger efficiency losses. Therefore, countries gain more from tax cooperation in a world with lower MP frictions.

Table 10: Sensitivity Analysis for Cooperative Corporate Taxes

| | No Profit Shifting | | | MP Liberalization | | |
|---|---|---|---|---|---|---|
| Changes in: | Welfare<br>(1) | Innovation Share<br>(2) | MP Share<br>(3) | Welfare<br>(4) | Innovation Share<br>(5) | MP Share<br>(6) |
| Belgium | 1.00 | 22.0 | -6.10 | 1.05 | 15.3 | -4.83 |
| Canada | 1.00 | 17.4 | 0.15 | 1.05 | 36.6 | -4.34 |
| Germany | 1.00 | 27.2 | -2.60 | 1.05 | 40.4 | -5.13 |
| France | 1.00 | 22.2 | -1.20 | 1.05 | 21.7 | -1.41 |
| U.K. | 1.00 | 22.9 | -1.53 | 1.05 | 27.5 | -3.44 |
| Ireland | 1.00 | -10.4 | 0.28 | 1.05 | -4.9 | -0.01 |
| The Netherlands | 1.00 | 3.8 | -2.53 | 1.05 | 9.9 | -4.56 |
| U.S. | 1.00 | 40.2 | -2.22 | 1.05 | 31.5 | -1.08 |
| ROW | 1.00 | 33.3 | -1.31 | 1.05 | 36.0 | -2.12 |

(Notes: All changes are relative to the factual equilibrium. MP liberalization refers to a 10 percent decrease in $\gamma_{i\ell}$ for all $i \neq \ell$. The MP share refers to the inward MP as a share of total production value. Changes in welfare and innovation share are measured by percentage changes. Changes in MP share are measured by changes in percentage points. The details of cooperative taxes under alternative parameter values can be seen in Appendix B.6.)

# 7 Conclusion

I propose a multi-country general equilibrium framework to quantify the welfare effects of corporate taxes. The model incorporates salient features of international corporate tax system into the quantitative MP model developed by ARRY (2018). I use this framework to provide a first quantitative assessment of international corporate tax competition and cooperation. I show that countries have incentives to impose lower corporate tax rates on domestic firms than on foreign firms, triggering firm relocation and gaining at the expense of others. When all countries manipulate their corporate taxes simultaneously, tax wars distort

that without profit shifting, cooperative tax rates have larger variation within and across countries.

the structure of corporate taxes in participation countries and lead to considerable welfare losses. Tax cooperation that corrects these distortions would thus benefit everyone.

Having abstracted from many features of reality, my quantitative model still provides the best framework to date for analyzing the consequences of international tax competition and cooperation. The extreme cases discussed in my quantitative analysis can serve as a useful input into policy debates and future academic research. An important feature omitted by my current framework is the technology spillovers from foreign MNEs to local firms, which is key for countries' incentives of manipulating their corporate taxes. I leave this aspect in the future extension of my work.

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# Appendix A Theories and Numerical Examples

## A.1 Expenditure Shares and Price Indices

In this subsection, I derive the aggregate variables such as trade and MP flows and price indices by solving the firm's problem. Denote

$$\chi_{ikn}(\omega) := \kappa_{ik} \frac{\xi_{ikn}}{z_k(\omega)}. \tag{36}$$

Notice that

$$H_{in}(\chi) := Pr\{\chi_{ikn}(\omega) \leq \chi \text{ for all } k\} = 1 - \exp\left\{ - \left[ \sum_{k \neq i} \left( A_k \left( \frac{\xi_{ikn}\kappa_{ik}}{\chi} \right)^{-\epsilon} \right)^{\frac{1}{1-\rho}} \right]^{1-\rho} - A_i \left( \frac{\xi_{iin}\kappa_{ii}}{\chi} \right)^{-\epsilon} \right\}. \tag{37}$$

Notably, the probability that firm $\omega$ from country $i$ produces at country $\ell$ to serve market $n$ is defined as

$$\zeta_{i\ell n} = Pr\left[ \chi_{i\ell n}(\omega) \leq \min\{\chi_{ikn}(\omega); k \neq \ell\} \right]. \tag{38}$$

Based on Equation (A1) of Ramondo and Rodriguez-Clare (2013), I get

$$\begin{aligned}
\zeta_{iin} &= \frac{A_i(\xi_{iin}\kappa_{ii})^{-\epsilon}}{\left[ \sum_{k \neq i} A_k(\xi_{ikn}\kappa_{ik})^{-\frac{\epsilon}{1-\rho}} \right]^{1-\rho} + A_i(\xi_{iin}\kappa_{ii})^{-\epsilon}}, \\
\zeta_{i\ell n} &= \frac{\left[ \sum_{k \neq i} A_k(\xi_{ikn}\kappa_{ik})^{-\frac{\epsilon}{1-\rho}} \right]^{1-\rho}}{\left[ \sum_{k \neq i} A_k(\xi_{ikn}\kappa_{ik})^{-\frac{\epsilon}{1-\rho}} \right]^{1-\rho} + A_i(\xi_{iin}\kappa_{ii})^{-\epsilon}} \frac{A_\ell(\xi_{i\ell n}\kappa_{i\ell})^{-\frac{\epsilon}{1-\rho}}}{\sum_{k \neq i} A_k(\xi_{ikn}\kappa_{ik})^{-\frac{\epsilon}{1-\rho}}}, \quad \ell \neq i.
\end{aligned} \tag{39}$$

Let $\tilde{C}_{in} = \left[ \sum_{k \neq i} A_k(\xi_{ikn}\kappa_{ik})^{-\frac{\epsilon}{1-\rho}} \right]^{1-\rho} + A_i(\xi_{iin}\kappa_{ii})^{-\epsilon}$. Then the distribution of $\chi_{i\ell n}(\omega)$ conditional on that firm $\omega$ actually produces in country $\ell$ is

$$Pr(\chi_{i\ell n}(\omega) \leq \chi | \chi_{i\ell n}(\omega) \leq \min\{\chi_{ikn}(\omega); k \neq \ell\}) = 1 - \exp\{-\tilde{C}_{in}\chi^{\epsilon}\}. \tag{40}$$

Notice that the cost $\tilde{\chi}_{i\ell n}(\omega)$ can be expressed as

$$\tilde{\chi}_{i\ell n}(\omega) = \frac{\chi_{i\ell n}(\omega)}{\kappa_{i\ell}}. \tag{41}$$

Let $X_{i\ell n}$ be the pre-tax sales of firms originated from country $i$ producing in country $\ell$ to country $n$ and $X_{in}$ be the pre-tax sales of firms originated from country $i$ to country $n$.

Then

$$
\begin{aligned}
\psi_{iin} &= \frac{A_i(\xi_{iin}\kappa_{ii})^{-\epsilon}\kappa_{ii}^{\sigma-1}}{\left[\sum_{k\neq i} A_k(\xi_{ikn}\kappa_{ik})^{-\frac{\epsilon}{1-\rho}}\right]^{-\rho}\sum_{k\neq i} A_k(\xi_{ikn}\kappa_{ik})^{-\frac{\epsilon}{1-\rho}}\kappa_{ik}^{\sigma-1} + A_i(\xi_{iin}\kappa_{ii})^{-\epsilon}\kappa_{ii}^{\sigma-1}}, \\
\psi_{i\ell n} &= \frac{\left[\sum_{k\neq i} A_k(\xi_{ikn}\kappa_{ik})^{-\frac{\epsilon}{1-\rho}}\right]^{-\rho} A_\ell(\xi_{i\ell n}\kappa_{i\ell})^{-\frac{\epsilon}{1-\rho}}\kappa_{i\ell}^{\sigma-1}}{\left[\sum_{k\neq i} A_k(\xi_{ikn}\kappa_{ik})^{-\frac{\epsilon}{1-\rho}}\right]^{-\rho}\sum_{k\neq i} A_k(\xi_{ikn}\kappa_{ik})^{-\frac{\epsilon}{1-\rho}}\kappa_{ik}^{\sigma-1} + A_i(\xi_{iin}\kappa_{ii})^{-\epsilon}\kappa_{ii}^{\sigma-1}}, \quad \ell \neq i.
\end{aligned} \tag{42}
$$

Let $\tilde{D}_{in} = \left[\sum_{k\neq i} A_k(\xi_{ikn}\kappa_{ik})^{-\frac{\epsilon}{1-\rho}}\right]^{-\rho}\sum_{k\neq i} A_k(\xi_{ikn}\kappa_{ik})^{-\frac{\epsilon}{1-\rho}}\kappa_{ik}^{\sigma-1} + A_i(\xi_{iin}\kappa_{ii})^{-\epsilon}\kappa_{ii}^{\sigma-1}$. Then the expected cost of firm $\omega$ from country $i$ to serve country $n$ can be given by

$$
\begin{aligned}
c_{in}(\omega) = E_z(\min_{\ell}\{c_{i\ell n}(\omega)\}) &= \frac{\tilde{\gamma}}{\varphi_i(\omega)}\left\{\sum_{\ell=1}^{N}\zeta_{i\ell n}\tilde{C}_{in}^{-\frac{1-\sigma}{\epsilon}}\kappa_{i\ell}^{\sigma-1}\right\}^{\frac{1}{1-\sigma}} \\
&= \frac{\tilde{\gamma}}{\varphi_i(\omega)}\tilde{C}_{in}^{-\frac{1}{\epsilon}-\frac{1}{1-\sigma}}\tilde{D}_{in}^{\frac{1}{1-\sigma}},
\end{aligned} \tag{43}
$$

where $\tilde{\gamma} = \left[\Gamma\left(\frac{\epsilon-(\sigma-1)}{\epsilon}\right)\right]^{\frac{1}{1-\sigma}}$ and $\Gamma(.)$ is the gamma function.

Accordingly, the post-tax-equivalent expected cost of $\omega$ from country $i$ to serve country $n$ can be given by

$$
\tilde{c}_{in}(\omega) = \frac{\tilde{\gamma}}{\varphi_i(\omega)}\tilde{C}_{in}^{-\frac{1}{\epsilon}}. \tag{44}
$$

Therefore, firm $\omega$ from country $i$ will serve market $n$ if and only if

$$
\begin{aligned}
&\frac{\tilde{\gamma}^{1-\sigma}}{\sigma}\tilde{\sigma}^{1-\sigma}X_n P_n^{\sigma-1}\tilde{C}_{in}^{-\frac{1-\sigma}{\epsilon}}\varphi_i(\omega)^{\sigma-1} \geq w_n F_n. \\
&\Leftrightarrow \varphi_i(\omega) \geq \varphi_{in}^{*} := \left\{\frac{w_n F_n}{\frac{\tilde{\gamma}^{1-\sigma}}{\sigma}\tilde{\sigma}^{1-\sigma}X_n P_n^{\sigma-1}\tilde{C}_{in}^{-\frac{1-\sigma}{\epsilon}}}\right\}^{\frac{1}{\sigma-1}}.
\end{aligned} \tag{45}
$$

Therefore, the pre-tax sales of firms originated from country $i$ to country $n$ can be expressed as

$$
\begin{aligned}
X_{in} &= M_i\tilde{\gamma}^{1-\sigma}\tilde{\sigma}^{1-\sigma}X_n P_n^{\sigma-1}\tilde{C}_{in}^{-\frac{1-\sigma}{\epsilon}}\left[\sum_{\ell=1}^{N}\zeta_{i\ell n}\kappa_{i\ell}^{\sigma-1}\right]\int_{\varphi_{in}^{*}}^{\infty}\varphi^{\sigma-1}dG_i(\varphi) \\
&= \tilde{\gamma}^{1-\sigma}\tilde{\sigma}^{1-\sigma}X_n P_n^{\sigma-1}\tilde{C}_{in}^{-\frac{1-\sigma}{\epsilon}}\left[\sum_{\ell=1}^{N}\zeta_{i\ell n}\kappa_{i\ell}^{\sigma-1}\right]\frac{\theta}{\theta-(\sigma-1)}M_i T_i\left(\varphi_{in}^{*}\right)^{-[\theta-(\sigma-1)]}.
\end{aligned} \tag{46}
$$

Let $\Phi_{in} = \tilde{C}_{in}^{-\frac{1}{\epsilon}}$ and $\Psi_{in} = \sum_{\ell=1}^{N} \zeta_{i\ell n} \kappa_{i\ell}^{\sigma-1}$. Therefore

$$X_{in} = \frac{\theta \sigma^{-\frac{\theta-(\sigma-1)}{\sigma-1}} \tilde{\gamma}^{-\theta} \tilde{\sigma}^{-\theta}}{\theta - (\sigma - 1)} M_i T_i \Phi_{in}^{-\theta} \Psi_{in} X_n P_n^{\theta} \left[ \frac{w_n F_n}{X_n} \right]^{-\frac{\theta-(\sigma-1)}{\sigma-1}}. \tag{47}$$

The pre-tax price index in country $n$ is thus

$$\begin{aligned} P_n^{1-\sigma} &= \sum_{i=1}^{N} \left[ \tilde{\gamma}^{1-\sigma} \tilde{\sigma}^{1-\sigma} M_i \Phi_{in}^{1-\sigma} \Psi_{in} \int_{\varphi_{in}^*}^{\infty} \varphi^{\sigma-1} dG_i(\varphi) \right] \\ \Rightarrow P_n^{-\theta} &= \frac{\theta \sigma^{-\frac{\theta-(\sigma-1)}{\sigma-1}} \tilde{\gamma}^{-\theta} \tilde{\sigma}^{-\theta}}{\theta - (\sigma - 1)} \sum_{i=1}^{N} M_i T_i \Phi_{in}^{-\theta} \Psi_{in} \left[ \frac{w_n F_n}{X_n} \right]^{-\frac{\theta-(\sigma-1)}{\sigma-1}}. \end{aligned} \tag{48}$$

The total fixed marketing cost associated with $X_{in}$ can be given by

$$M_i w_n F_n \int_{\varphi_{in}^*}^{\infty} dG_i(\varphi) = \frac{\theta - (\sigma - 1)}{\theta \sigma} \frac{X_{in}}{\Psi_{in}}. \tag{49}$$

## A.2 Equilibrium in Relative Changes

First, the changes in $\kappa_{i\ell}$ can be expressed by

$$\hat{\kappa}_{i\ell} \kappa_{i\ell} = \left\{ 1 - \tilde{\kappa}_{i\ell}' + \sum_{k=1}^{N} \left[ (\tilde{\kappa}_{i\ell}' - \tilde{\kappa}_{ik}') \max \left\{ \frac{\tilde{\kappa}_{i\ell}' - \tilde{\kappa}_{ik}'}{\tilde{\eta} / \left(\lambda_{ik}^{MP}\right)'}, 0 \right\} - \frac{1}{2} \frac{\tilde{\eta}}{\left(\lambda_{ik}^{MP}\right)'} \max \left\{ \frac{\tilde{\kappa}_{i\ell}' - \tilde{\kappa}_{ik}'}{\tilde{\eta} / \left(\lambda_{ik}^{MP}\right)'}, 0 \right\}^2 \right] \right\}^{\frac{1}{1-\sigma}}. \tag{50}$$

Let $\Xi_{in} = \sum_{k \neq i} A_k \left( \xi_{ikn} \kappa_{ik} \right)^{-\frac{\epsilon}{1-\rho}}$. Notice that $\hat{\xi}_{i\ell n} = \hat{\gamma}_{i\ell} \hat{w}_{\ell}^{p} \hat{\tau}_{\ell n}$. Then I have

$$\hat{\Xi}_{in} = \sum_{k \neq i} \frac{\zeta_{ikn}}{\sum_{k' \neq i} \zeta_{ik'n}} \left( \hat{\xi}_{ikn} \hat{\kappa}_{ik} \right)^{-\frac{\epsilon}{1-\rho}}. \tag{51}$$

Henceforth,

$$\begin{aligned} \hat{\zeta}_{iin} &= \frac{\left( \hat{\xi}_{iin} \hat{\kappa}_{ii} \right)^{-\epsilon}}{\hat{\Xi}_{in}^{-\rho} \sum_{k \neq i} \zeta_{ikn} \left( \hat{\xi}_{ikn} \hat{\kappa}_{ik} \right)^{-\frac{\epsilon}{1-\rho}} + \zeta_{iin} \left( \hat{\xi}_{iin} \hat{\kappa}_{ii} \right)^{-\epsilon}} \\ \hat{\zeta}_{i\ell n} &= \frac{\hat{\Xi}_{in}^{-\rho} \left( \hat{\xi}_{i\ell n} \hat{\kappa}_{i\ell} \right)^{-\frac{\epsilon}{1-\rho}}}{\hat{\Xi}_{in}^{-\rho} \sum_{k \neq i} \zeta_{ikn} \left( \hat{\xi}_{ikn} \hat{\kappa}_{ik} \right)^{-\frac{\epsilon}{1-\rho}} + \zeta_{iin} \left( \hat{\xi}_{iin} \hat{\kappa}_{ii} \right)^{-\epsilon}} \end{aligned} \tag{52}$$

Moreover,

$$\hat{\psi}_{iin} = \frac{\left(\hat{\xi}_{iin}\hat{\kappa}_{ii}\right)^{-\epsilon}\hat{\kappa}_{ii}^{\sigma-1}}{\hat{\Xi}_{in}^{-\rho}\sum_{k\neq i}\psi_{ikn}\left(\hat{\xi}_{ikn}\hat{\kappa}_{ik}\right)^{-\frac{\epsilon}{1-\rho}}\hat{\kappa}_{ik}^{\sigma-1}+\psi_{iin}\left(\hat{\xi}_{iin}\hat{\kappa}_{ii}\right)^{-\epsilon}\hat{\kappa}_{ii}^{\sigma-1}}$$
$$\hat{\psi}_{i\ell n} = \frac{\hat{\Xi}_{in}^{-\rho}\left(\hat{\xi}_{i\ell n}\hat{\kappa}_{i\ell}\right)^{-\frac{\epsilon}{1-\rho}}\hat{\kappa}_{i\ell}^{\sigma-1}}{\hat{\Xi}_{in}^{-\rho}\sum_{k\neq i}\psi_{ikn}\left(\hat{\xi}_{ikn}\hat{\kappa}_{ik}\right)^{-\frac{\epsilon}{1-\rho}}\hat{\kappa}_{ik}^{\sigma-1}+\psi_{iin}\left(\hat{\xi}_{iin}\hat{\kappa}_{ii}\right)^{-\epsilon}\hat{\kappa}_{ii}^{\sigma-1}} \tag{53}$$

Notice that

$$\hat{\Phi}_{in} = \left\{\hat{\Xi}_{in}^{-\rho}\sum_{k\neq i}\zeta_{ikn}\left(\hat{\xi}_{ikn}\hat{\kappa}_{ik}\right)^{-\frac{\epsilon}{1-\rho}}+\zeta_{iin}\left(\hat{\xi}_{iin}\hat{\kappa}_{ii}\right)^{-\epsilon}\right\}^{-\frac{1}{\epsilon}}, \tag{54}$$

and

$$\hat{\Psi}_{in} = \sum_{k=1}^{N}\psi_{ikn}\hat{\zeta}_{ikn}\hat{\kappa}_{ik}^{\sigma-1}. \tag{55}$$

Therefore,

$$\hat{\lambda}_{in} = \frac{\hat{M}_i\hat{\Phi}_{in}^{-\theta}\hat{\Psi}_{in}}{\sum_{h=1}^{N}\lambda_{hn}\hat{M}_h\hat{\Phi}_{hn}^{-\theta}\hat{\Psi}_{hn}}. \tag{56}$$

Let $X'_{i\ell n} = \psi'_{i\ell n}\lambda'_{in}\hat{X}_n X_n$ and $X'_{in} = \sum_k X'_{ikn}$. Notice that

$$\left(\lambda_{i\ell}^{MP}\right)' = \frac{\sum_n X'_{i\ell n}}{\sum_{\ell,n} X'_{i\ell n}}. \tag{57}$$

$\hat{L}_i^p$ can be expressed as

$$\hat{w}_i^p\hat{L}_i^p w_i^p L_i^p = \left(1-\frac{1}{\sigma}\right)\sum_{k,n}X'_{kin} + \delta\sum_k\frac{X'_{ki}}{\Psi'_{ki}}. \tag{58}$$

$\hat{w}_i^e$ and $\hat{M}_i$ can be computed by

$$\hat{w}_i^e\hat{L}_i^e w_i^e L_i^e = \hat{M}_i\hat{w}_i^e M_i w_i^e f^e = \sum_{\ell,n}\left[\frac{1}{\sigma}\left(\kappa'_{i\ell}\right)^{1-\sigma}X'_{i\ell n} - \delta\zeta'_{i\ell n}\frac{X'_{in}}{\Psi'_{in}}\right]. \tag{59}$$

$\hat{X}_i$ can be computed from:

$$\hat{X}_i X_i = \hat{w}_i^p\hat{L}_i^p w_i^p L_i^p + \hat{w}_i^e\hat{L}_i^e w_i^e L_i^e + \Lambda'_i, \tag{60}$$

where

$$\Lambda'_\ell = \sum_{i,k,n} \frac{1}{\sigma} \tilde{\kappa}'_{i\ell} \left(1 - \max\left\{ \frac{\tilde{\kappa}'_{i\ell} - \tilde{\kappa}'_{ik}}{\tilde{\eta}/\left(\lambda_{ik}^{MP}\right)'}, 0 \right\}\right) X'_{i\ell n} + \sum_{i,k,n} \frac{1}{2} \frac{\tilde{\eta}}{\left(\lambda_{ik}^{MP}\right)'} \max\left\{ \frac{\tilde{\kappa}'_{i\ell} - \tilde{\kappa}'_{ik}}{\tilde{\eta}/\left(\lambda_{ik}^{MP}\right)'}, 0 \right\}^2 \frac{1}{\sigma} X'_{i\ell n} + \sum_{i,k,n} \frac{1}{\sigma} \tilde{\kappa}'_{i\ell} \max\left\{ \frac{\tilde{\kappa}'_{ik} - \tilde{\kappa}'_{i\ell}}{\tilde{\eta}/\left(\lambda_{i\ell}^{MP}\right)'}, 0 \right\} X'_{ikn}. \tag{61}$$

The changes in price are given by

$$\hat{P}_n^{-\theta} = \left(\frac{\hat{w}_n^p}{\hat{X}_n}\right)^{-\frac{\theta-(\sigma-1)}{\sigma-1}} \left\{ \sum_{i=1}^{N} \lambda_{in} \hat{M}_i \hat{\Phi}_{in}^{-\theta} \hat{\Psi}_{in} \right\}. \tag{62}$$

Let $Y_i = w_i^e L_i^e + w_i^p L_i^p$. Labor allocation implies that $Y_i = \left[(w_i^e)^\mu + (w_i^p)^\mu\right]^{\frac{1}{\mu}} \bar{L}_i$. Then changes in labor allocation can be given by

$$\hat{L}_i^e = \left(\frac{\hat{w}_i^e}{\hat{Y}_i}\right)^{\mu-1}, \quad \hat{L}_i^p = \left(\frac{\hat{w}_i^p}{\hat{Y}_i}\right)^{\mu-1}, \tag{63}$$

where

$$\hat{Y}_i = \hat{w}_i^e \hat{L}_i^e \frac{w_i^e L_i^e}{Y_i} + \hat{w}_i^p \hat{L}_i^p \frac{w_i^p L_i^p}{Y_i}. \tag{64}$$

Finally, changes in the government's objective can be given as

$$\hat{W}_i = \frac{\hat{X}_i}{\hat{P}_i}. \tag{65}$$

## A.3 Proof to Proposition 2

**Proof.**

The tax revenue is

$$\Lambda = \frac{1}{\sigma}\left(1 - \kappa^{1-\sigma}\right) X. \tag{66}$$

The wage income for production workers is

$$w^p L^p = \left(1 - \frac{1}{\sigma}\right) X + \delta \kappa^{1-\sigma} X. \tag{67}$$

The wage income for innovation workers is

$$w^e L^e = \frac{1}{\sigma} \kappa^{1-\sigma} X - \delta \kappa^{1-\sigma} X. \tag{68}$$

Labor allocation is determined by

$$L^e = \left[1 + \left(\frac{w_i^e}{w_i^p}\right)^{-\mu}\right]^{\frac{1}{\mu}-1} \bar{L}, \quad L^p = \left[1 + \left(\frac{w_i^e}{w_i^p}\right)^{\mu}\right]^{\frac{1}{\mu}-1} \bar{L}. \tag{69}$$

The total expenditure is given by

$$X = w^p L^p + w^e L^e + \Lambda. \tag{70}$$

Notice that

$$\frac{w^e L^e}{w^p L^p} = \left(\frac{w^e}{w^p}\right)^{\mu} = \frac{\frac{1}{\sigma}\kappa^{1-\sigma} - \delta\kappa^{1-\sigma}}{\left(1-\frac{1}{\sigma}\right) + \delta\kappa^{1-\sigma}}. \tag{71}$$

Normalize $w^p = 1$. Then

$$w^e = \left[\frac{\frac{1}{\sigma} - \delta}{\left(1-\frac{1}{\sigma}\right)\kappa^{\sigma-1} + \delta}\right]^{\frac{1}{\mu}}. \tag{72}$$

And

$$\begin{aligned} X &= \frac{1}{1-\frac{1}{\sigma}(1-\kappa^{1-\sigma})} \left[(w^e)^{\mu} + (w^p)^{\mu}\right]^{\frac{1}{\mu}} \bar{L} \\ &= \frac{\bar{L}}{1-\frac{1}{\sigma}(1-\kappa^{1-\sigma})} \left[1 + \frac{\frac{1}{\sigma} - \delta}{\left(1-\frac{1}{\sigma}\right)\kappa^{\sigma-1} + \delta}\right]^{\frac{1}{\mu}} \\ &= \frac{\bar{L}}{1-\frac{1}{\sigma}(1-\kappa^{1-\sigma})} \left[\frac{1-\frac{1}{\sigma}(1-\kappa^{1-\sigma})}{\left(1-\frac{1}{\sigma}\right) + \delta\kappa^{1-\sigma}}\right]^{\frac{1}{\mu}}. \end{aligned} \tag{73}$$

Also

$$L^e = \frac{1}{w^e}\kappa^{1-\sigma}\left(\frac{1}{\sigma} - \delta\right) X. \tag{74}$$

The price index is given by

$$P^{-\theta} \propto \left[\frac{X}{w^p}\right]^{\frac{\theta-(\sigma-1)}{\sigma-1}} L^e \kappa^{-[\theta-(\sigma-1)]}. \tag{75}$$

The welfare can be expressed as

$$
\begin{aligned}
W &= \frac{X}{P} = X^{1+\frac{\theta-(\sigma-1)}{\theta(\sigma-1)}} \left(L^{e}\right)^{\frac{1}{\theta}} \kappa^{-\frac{\theta-(\sigma-1)}{\theta}} \\
&\propto X^{\frac{\sigma}{\sigma-1}} \kappa^{-1} \left(w^{e}\right)^{-\frac{1}{\theta}} \\
&\propto \left[1-\frac{1}{\sigma}\left(1-\kappa^{1-\sigma}\right)\right]^{-\frac{\sigma}{\sigma-1}} \kappa^{-1} \left[\frac{\left[1-\frac{1}{\sigma}\left(1-\kappa^{1-\sigma}\right)\right]^{\frac{\sigma}{\sigma-1}} \kappa^{\frac{\sigma-1}{\theta}}}{\left[\left(1-\frac{1}{\sigma}\right)+\delta\kappa^{1-\sigma}\right]^{\frac{\sigma}{\sigma-1}-\frac{1}{\theta}}}\right]^{\frac{1}{\mu}}.
\end{aligned} \tag{76}
$$

Notice that $\delta := \frac{\theta-(\sigma-1)}{\theta\sigma}$.

The optimal corporate tax is welfare-maximizing, i.e. $\frac{\partial \log W}{\partial \kappa} = 0$. Then

$$
\kappa^{*} = 1 \Rightarrow 1-\tilde{\kappa}^{*} = 1. \tag{77}
$$

■

## A.4 Proof to Proposition 3

**Proof.**

In this example, we have $w_i^p = w_i^e = w_i$ and $\xi_{i\ell n} = w_\ell$ for all $(i, \ell, n)$. Then

$$
\zeta_{i\ell n} = \frac{\left(w_i \kappa_{i\ell}\right)^{-\epsilon}}{\sum_k \left(w_k \kappa_{ik}\right)^{-\epsilon}}, \tag{78}
$$

and

$$
\psi_{i\ell n} = \frac{\left(w_i \kappa_{i\ell}\right)^{-\epsilon} \kappa_{i\ell}^{\sigma-1}}{\sum_k \left(w_k \kappa_{ik}\right)^{-\epsilon} \kappa_{ik}^{\sigma-1}}. \tag{79}
$$

Moreover,

$$
\Phi_{in} = \left[\sum_k \left(w_k \kappa_{ik}\right)^{-\epsilon}\right]^{-\frac{1}{\epsilon}}, \tag{80}
$$

and

$$
\Psi_{in} = \frac{\sum_k \left(w_k \kappa_{ik}\right)^{-\epsilon} \kappa_{ik}^{\sigma-1}}{\sum_k \left(w_k \kappa_{ik}\right)^{-\epsilon}}. \tag{81}
$$

Therefore,

$$
\lambda_{in} = \frac{M_i \left[\sum_k \left(w_k \kappa_{ik}\right)^{-\epsilon}\right]^{\frac{\theta}{\epsilon}-1} \sum_k \left(w_k \kappa_{ik}\right)^{-\epsilon} \kappa_{ik}^{\sigma-1}}{\sum_h M_h \left[\sum_k \left(w_k \kappa_{hk}\right)^{-\epsilon}\right]^{\frac{\theta}{\epsilon}-1} \sum_k \left(w_k \kappa_{hk}\right)^{-\epsilon} \kappa_{hk}^{\sigma-1}}. \tag{82}
$$

So

$$X_{i\ell n} = \psi_{i\ell n}\lambda_{in}X_n = \frac{M_i\left[\sum_k \left(w_k\kappa_{ik}\right)^{-\epsilon}\right]^{\frac{\theta}{\epsilon}-1}\left(w_\ell\kappa_{i\ell}\right)^{-\epsilon}\kappa_{i\ell}^{\sigma-1}}{\sum_h M_h\left[\sum_k \left(w_k\kappa_{hk}\right)^{-\epsilon}\right]^{\frac{\theta}{\epsilon}-1}\sum_k \left(w_k\kappa_{hk}\right)^{-\epsilon}\kappa_{hk}^{\sigma-1}}X_n. \tag{83}$$

Labor market clearing:

$$w_i = \left(1-\frac{1}{\sigma}\right)\sum_{k,n} X_{kin} + \frac{1}{\sigma}\sum_{\ell,n}\kappa_{i\ell}^{1-\sigma}X_{i\ell n}. \tag{84}$$

Current account balance:

$$X_i = w_i + \frac{1}{\sigma}\sum_{k,n}\left(1-\kappa_{ki}^{1-\sigma}\right)X_{kin}. \tag{85}$$

Free entry:

$$M_i w_i = \frac{1}{\sigma}\sum_{\ell,n}\kappa_{i\ell}^{1-\sigma}X_{i\ell n}. \tag{86}$$

Price:

$$P_i^{-\theta} = P^{-\theta} = \sum_h M_h\left[\sum_k \left(w_k\kappa_{hk}\right)^{-\epsilon}\right]^{\frac{\theta}{\epsilon}-1}\sum_k \left(w_k\kappa_{hk}\right)^{-\epsilon}\kappa_{hk}^{\sigma-1}. \tag{87}$$

Normalize $w_1 = 1$. Let $X = X_1 + X_2$. Then

$$\begin{aligned}
1 &= X\frac{\left(1-\frac{1}{\sigma}\right)M_2\left(\kappa_{21}^{-\epsilon}+w_2^{-\epsilon}\right)^{-\frac{1}{\epsilon}(\epsilon-\theta)}\kappa_{21}^{-[\epsilon-(\sigma-1)]} + M_1\left(\kappa_{11}^{-\epsilon}+w_2^{-\epsilon}\right)^{-\frac{1}{\epsilon}(\epsilon-\theta)}\left(\frac{1}{\sigma}w_2^{-\epsilon}+\frac{1}{\sigma}\kappa_{11}^{-\epsilon}+\left(1-\frac{1}{\sigma}\right)\kappa_{11}^{-[\epsilon-(\sigma-1)]}\right)}{M_1\left(\kappa_{11}^{-\epsilon}+w_2^{-\epsilon}\right)^{-\frac{1}{\epsilon}(\epsilon-\theta)}\left(\kappa_{11}^{-[\epsilon-(\sigma-1)]}+w_2^{-\epsilon}\right) + M_2\left(\kappa_{21}^{-\epsilon}+w_2^{-\epsilon}\right)^{-\frac{1}{\epsilon}(\epsilon-\theta)}\left(\kappa_{21}^{-[\epsilon-(\sigma-1)]}+w_2^{-\epsilon}\right)}\\
w_2 &= X\frac{\left(1-\frac{1}{\sigma}\right)M_1\left(\kappa_{11}^{-\epsilon}+w_2^{-\epsilon}\right)^{-\frac{1}{\epsilon}(\epsilon-\theta)}w_2^{-\epsilon} + M_2\left(\kappa_{21}^{-\epsilon}+w_2^{-\epsilon}\right)^{-\frac{1}{\epsilon}(\epsilon-\theta)}\left(\frac{1}{\sigma}\kappa_{21}^{-\epsilon}+w_2^{-\epsilon}\right)}{M_1\left(\kappa_{11}^{-\epsilon}+w_2^{-\epsilon}\right)^{-\frac{1}{\epsilon}(\epsilon-\theta)}\left(\kappa_{11}^{-[\epsilon-(\sigma-1)]}+w_2^{-\epsilon}\right) + M_2\left(\kappa_{21}^{-\epsilon}+w_2^{-\epsilon}\right)^{-\frac{1}{\epsilon}(\epsilon-\theta)}\left(\kappa_{21}^{-[\epsilon-(\sigma-1)]}+w_2^{-\epsilon}\right)}\\
X_2 &= w_2\\
X_1 &= 1+\frac{1}{\sigma}X\frac{(1-\kappa_{11}^{1-\sigma})M_1\left(\kappa_{11}^{-\epsilon}+w_2^{-\epsilon}\right)^{-\frac{1}{\epsilon}(\epsilon-\theta)}\kappa_{11}^{-[\epsilon-(\sigma-1)]} + (1-\kappa_{21}^{1-\sigma})M_2\left(\kappa_{21}^{-\epsilon}+w_2^{-\epsilon}\right)^{-\frac{1}{\epsilon}(\epsilon-\theta)}\kappa_{21}^{-[\epsilon-(\sigma-1)]}}{M_1\left(\kappa_{11}^{-\epsilon}+w_2^{-\epsilon}\right)^{-\frac{1}{\epsilon}(\epsilon-\theta)}\left(\kappa_{11}^{-[\epsilon-(\sigma-1)]}+w_2^{-\epsilon}\right) + M_2\left(\kappa_{21}^{-\epsilon}+w_2^{-\epsilon}\right)^{-\frac{1}{\epsilon}(\epsilon-\theta)}\left(\kappa_{21}^{-[\epsilon-(\sigma-1)]}+w_2^{-\epsilon}\right)}\\
M_1 &= \frac{1}{\sigma}X\frac{M_1\left(\kappa_{11}^{-\epsilon}+w_2^{-\epsilon}\right)^{\frac{\theta}{\epsilon}}}{M_1\left(\kappa_{11}^{-\epsilon}+w_2^{-\epsilon}\right)^{-\frac{1}{\epsilon}(\epsilon-\theta)}\left(\kappa_{11}^{-[\epsilon-(\sigma-1)]}+w_2^{-\epsilon}\right) + M_2\left(\kappa_{21}^{-\epsilon}+w_2^{-\epsilon}\right)^{-\frac{1}{\epsilon}(\epsilon-\theta)}\left(\kappa_{21}^{-[\epsilon-(\sigma-1)]}+w_2^{-\epsilon}\right)}\\
M_2 w_2 &= \frac{1}{\sigma}X\frac{M_2\left(\kappa_{21}^{-\epsilon}+w_2^{-\epsilon}\right)^{\frac{\theta}{\epsilon}}}{M_1\left(\kappa_{11}^{-\epsilon}+w_2^{-\epsilon}\right)^{-\frac{1}{\epsilon}(\epsilon-\theta)}\left(\kappa_{11}^{-[\epsilon-(\sigma-1)]}+w_2^{-\epsilon}\right) + M_2\left(\kappa_{21}^{-\epsilon}+w_2^{-\epsilon}\right)^{-\frac{1}{\epsilon}(\epsilon-\theta)}\left(\kappa_{21}^{-[\epsilon-(\sigma-1)]}+w_2^{-\epsilon}\right)}
\end{aligned} \tag{88}$$

Then $w_2$ can be expressed as

$$w_2 = \left( \frac{\kappa_{21}^{-\epsilon} + w_2^{-\epsilon}}{\kappa_{11}^{-\epsilon} + w_2^{-\epsilon}} \right)^{\frac{\theta}{\epsilon}}. \tag{89}$$

Total differentiation of Equation (89) leads to the second result.

Given $w_2$, $(M_1, M_2)$ can be solved by

$$\begin{aligned} M_1 \frac{\frac{1}{\sigma} w_2^{-\epsilon} + \frac{1}{\sigma} \kappa_{11}^{-\epsilon} + \left(1 - \frac{1}{\sigma}\right) \kappa_{11}^{-[\epsilon-(\sigma-1)]}}{\kappa_{11}^{-\epsilon} + w_2^{-\epsilon}} + M_2 w_2 \frac{\left(1 - \frac{1}{\sigma}\right) \kappa_{21}^{-[\epsilon-(\sigma-1)]}}{\kappa_{21}^{-\epsilon} + w_2^{-\epsilon}} &= \frac{1}{\sigma}. \\ M_1 \frac{\left(1 - \frac{1}{\sigma}\right) w_2^{-\epsilon}}{\kappa_{11}^{-\epsilon} + w_2^{-\epsilon}} + M_2 w_2 \frac{\frac{1}{\sigma} \kappa_{21}^{-\epsilon} + w_2^{-\epsilon}}{\kappa_{21}^{-\epsilon} + w_2^{-\epsilon}} &= \frac{1}{\sigma} w_2. \end{aligned} \tag{90}$$

Then

$$\begin{aligned} M_1 &= \frac{1}{\sigma} \frac{\left(\kappa_{11}^{-\epsilon} + w_2^{-\epsilon}\right) \left[ w_2^{-\epsilon} + \frac{1}{\sigma} \kappa_{21}^{-\epsilon} - \left(1 - \frac{1}{\sigma}\right) w_2 \kappa_{21}^{-[\epsilon-(\sigma-1)]} \right]}{\left[ \frac{1}{\sigma} w_2^{-\epsilon} + \frac{1}{\sigma} \kappa_{11}^{-\epsilon} + \left(1 - \frac{1}{\sigma}\right) \kappa_{11}^{-[\epsilon-(\sigma-1)]} \right] \left[ \frac{1}{\sigma} \kappa_{21}^{-\epsilon} + w_2^{-\epsilon} \right] - \left(1 - \frac{1}{\sigma}\right)^2 w_2^{-\epsilon} \kappa_{21}^{-[\epsilon-(\sigma-1)]}} \\ M_2 &= \frac{1}{\sigma} \frac{\left(\kappa_{21}^{-\epsilon} + w_2^{-\epsilon}\right) \left[ w_2 \frac{1}{\sigma} \kappa_{11}^{-\epsilon} + w_2 \left(1 - \frac{1}{\sigma}\right) \kappa_{11}^{-[\epsilon-(\sigma-1)]} + \left( \frac{1}{\sigma} w_2 - \left(1 - \frac{1}{\sigma}\right)\right) w_2^{-\epsilon} \right]}{\left[ \frac{1}{\sigma} w_2^{-\epsilon} + \frac{1}{\sigma} \kappa_{11}^{-\epsilon} + \left(1 - \frac{1}{\sigma}\right) \kappa_{11}^{-[\epsilon-(\sigma-1)]} \right] \left[ \frac{1}{\sigma} \kappa_{21}^{-\epsilon} + w_2^{-\epsilon} \right] - \left(1 - \frac{1}{\sigma}\right)^2 w_2^{-\epsilon} \kappa_{21}^{-[\epsilon-(\sigma-1)]}} \end{aligned}. \tag{91}$$

Total differentiation of Equation (91) and (89) leads to the first result.

Moreover,

$$X_1 = 1 + M_1 \frac{\left(1 - \kappa_{11}^{1-\sigma}\right) \kappa_{11}^{-[\epsilon-(\sigma-1)]}}{\kappa_{11}^{-\epsilon} + w_2^{-\epsilon}} + M_2 w_2 \frac{\left(1 - \kappa_{21}^{1-\sigma}\right) \kappa_{21}^{-[\epsilon-(\sigma-1)]}}{\kappa_{21}^{-\epsilon} + w_2^{-\epsilon}}, \tag{92}$$

and

$$P = \left\{ M_1 \left(\kappa_{11}^{-\epsilon} + w_2^{-\epsilon}\right)^{-\frac{1}{\epsilon}(\epsilon-\theta)} \left( \kappa_{11}^{-[\epsilon-(\sigma-1)]} + w_2^{-\epsilon} \right) + M_2 \left(\kappa_{21}^{-\epsilon} + w_2^{-\epsilon}\right)^{-\frac{1}{\epsilon}(\epsilon-\theta)} \left( \kappa_{21}^{-[\epsilon-(\sigma-1)]} + w_2^{-\epsilon} \right) \right\}^{-\frac{1}{\theta}}. \tag{93}$$

Total differentiation of Equation (91), (92), (93), and (89) leads to the third result.

■

## A.5 Optimal Corporate Taxation in Special Cases

First, I compute the welfare of country 1 in the space of $(\tilde{\kappa}_{11}, \tilde{\kappa}_{21})$. The parameter values are as follows: $N = 2$, $A_i = T_i = \bar{L}_i = 1$, $\gamma_{i\ell} = \tau_{\ell n} = 1$ for all $(i, \ell, n)$, $\mu = 3$, $\theta = \sigma = 4$, $\epsilon = 6$, and $\tilde{\eta} = \infty$. The results are illustrated by Figure A.1. Consistent with Proposition 3, $W_1$ is increasing with $\tilde{\kappa}_{21}$ but decreasing with $\tilde{\kappa}_{11}$ at the point $(\tilde{\kappa}_{11}, \tilde{\kappa}_{21}) = (0, 0)$.

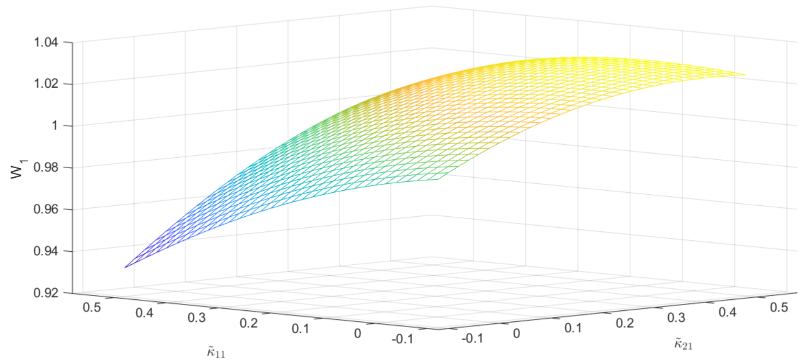



Figure A.1: The Real Income of Country 1 in the Two-Country Example

(Note: $W_1$ is normalized relative to its level under $\tilde{\kappa}_{11} = \tilde{\kappa}_{21} = 0$. The optimal tax for country 1 is $(\tilde{\kappa}_{11}^*, \tilde{\kappa}_{21}^*) = (0.0678, 0.4692)$.)

I then compute the optimal corporate tax rate in country 1 under the restriction that $\tilde{\kappa}_{11} = \tilde{\kappa}_{21} = \tilde{\kappa}$. Figure A.2 shows that the optimal corporate tax rate is strictly positive even if country 1 has to impose identical tax rates on domestic and foreign firms.

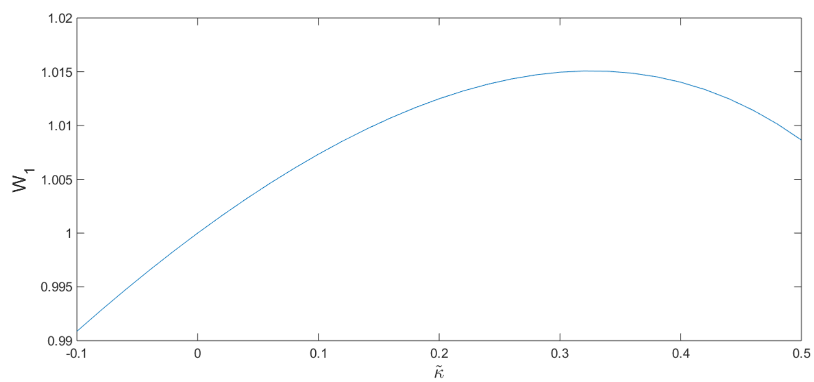



Figure A.2: The Real Income of Country 1 in the Two-Country Example

(Note: $W_1$ is normalized relative to its level under $\tilde{\kappa}_{11} = \tilde{\kappa}_{21} = 0$. I impose the restriction in which $\tilde{\kappa}_{11} = \tilde{\kappa}_{21} = \tilde{\kappa}$.)

Starting from the two-symmetric-country example above, I increase $\gamma = \gamma_{12} = \gamma_{21}$ from 1 to 2, computing optimal taxes under each value of $\gamma$. The result is illustrated by Figure A.3. The welfare gains from optimal taxes are illustrated by Figure A.4, suggesting that a country gain more from implementing optimal corporate taxes as it becomes more open to MP.

I then consider the two-symmetric-country example starting from the following parameter values: $N = 2$, $A_i = T_i = \bar{L}_i = 1$, $\gamma_{i\ell} = \tau_{\ell n} = 1.2$ for all $i \neq \ell$ and $\ell \neq n$, $\mu = 3$, $\theta = \sigma = 4$, $\epsilon = 6$, and $\tilde{\eta} = \infty$. I increase $A_1$ from 1 to 2 and compute optimal taxes accordingly. The

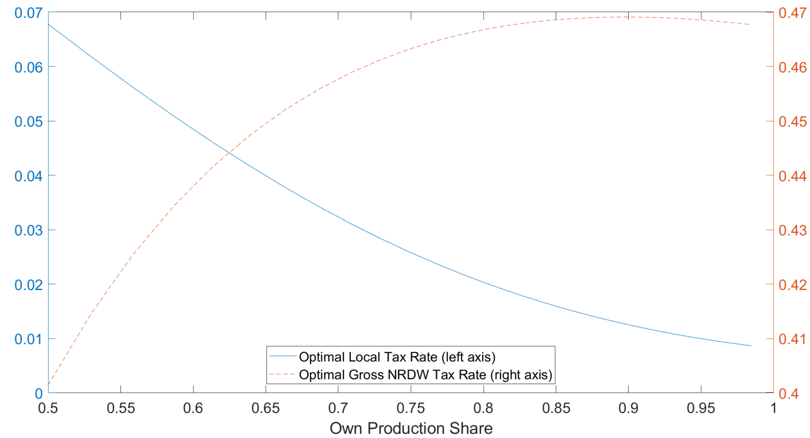



Figure A.3: Optimal Corporate Tax Rates under MP Liberalization

(Note: I increase $\gamma = \gamma_{12} = \gamma_{21}$ from 1 to 2. Own production share is defined as $X_{11}^{MP} / \left(X_{11}^{MP} + X_{21}^{MP}\right)$ in the tax-free world.)

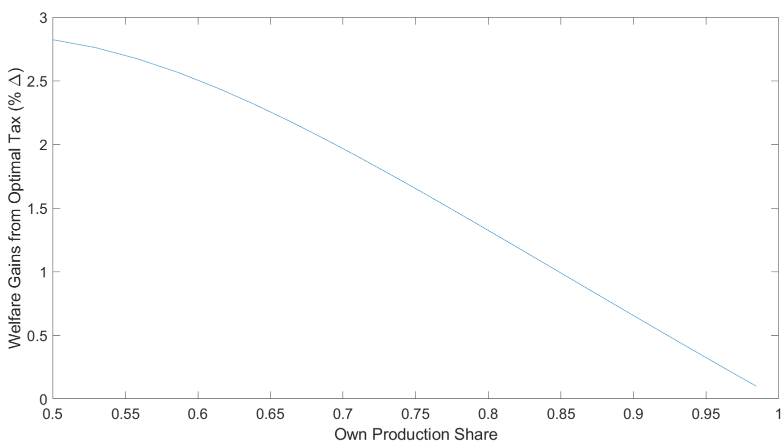



Figure A.4: Welfare Gains from Optimal Corporate Taxes under MP Liberalization

(Note: I increase $\gamma = \gamma_{12} = \gamma_{21}$ from 1 to 2. Own production share is defined as $X_{11}^{MP} / \left(X_{11}^{MP} + X_{21}^{MP}\right)$ in the tax-free world. Welfare gains from optimal taxes are relative to the welfare in the tax-free world.)

result is illustrated by Figure A.5. The welfare gains from optimal taxes are illustrated by Figure A.6, suggesting that a country with stronger comparative advantage in production gain more from implementing optimal corporate taxes.

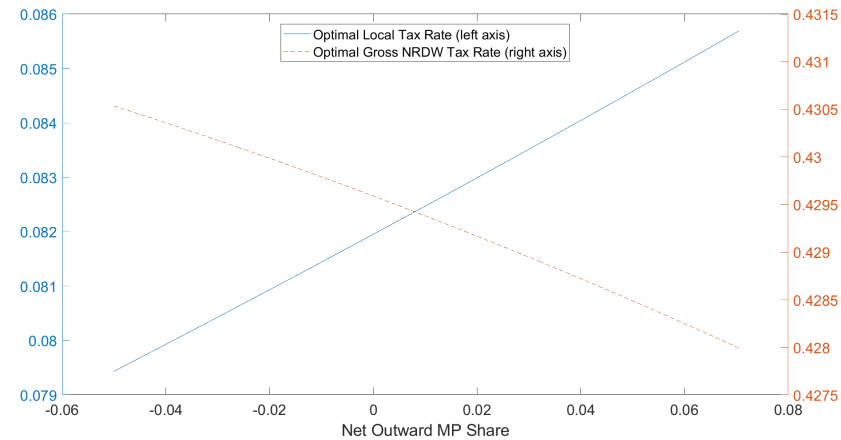



Figure A.5: Optimal Taxes and Specialization in Innovation/Production

(Note: I increase $A_1$ from 1 to 2. Net outward MP share is defined as $(X_{12}^{MP} - X_{21}^{MP})/(X_{12}^{MP} + X_{21}^{MP})$ in the tax-free world.)

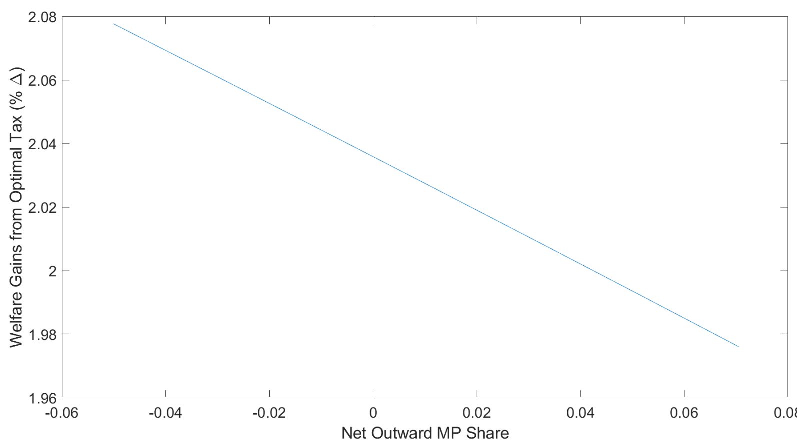
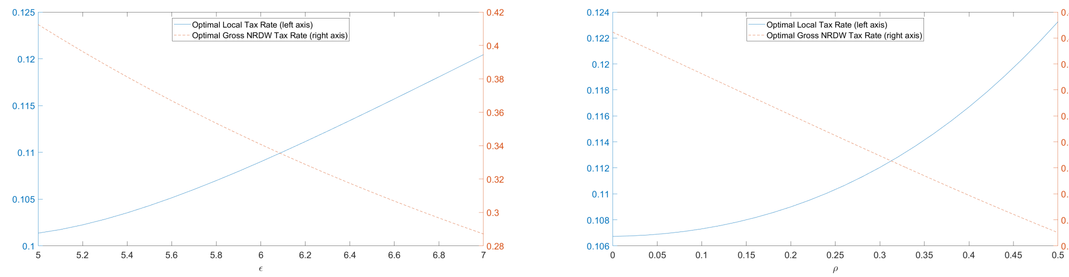


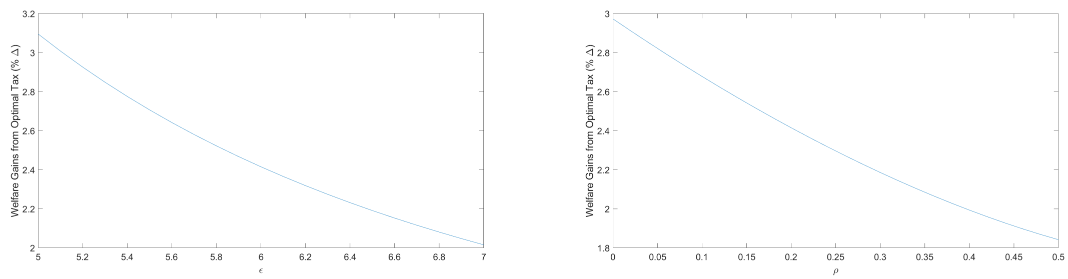

Figure A.6: Welfare Gains from Optimal Taxes and Specialization in Innovation/Production

(Note: I increase $A_1$ from 1 to 2. Net outward MP share is defined as $(X_{12}^{MP} - X_{21}^{MP})/(X_{12}^{MP} + X_{21}^{MP})$ in the tax-free world. Welfare gains from optimal taxes are relative to the welfare in the tax-free world.)

Then I turn to a three-country example, starting from $N = 3$, $\gamma_{i\ell} = \tau_{\ell n} = 1.2$ for all $i \neq \ell$ and $\ell \neq n$, $A_i = T_i = \bar{L}_i = 1$ for all $i$, $\tilde{\eta} = \infty$, $\theta = \sigma = 4$, $\epsilon = 6$, and $\rho = 0.2$. I change $\epsilon$ ($\rho$) and compute the optimal tax rates accordingly. The results are illustrated by Figure A.7.




(a) Optimal Tax w.r.t. $\epsilon$ (b) Optimal Tax w.r.t. $\rho$




(c) Gains from Optimal Tax w.r.t. $\epsilon$ (d) Gains from Optimal Tax w.r.t. $\rho$

Figure A.7: Optimal Taxes and the Firm's Responsiveness
(Note: Welfare gains from optimal taxes are relative to the welfare in the tax-free world.)

## A.6 Residence-Based Corporate Tax System

Although residence-based corporate taxes collected by source countries are less prevail than the corporate taxes collected by host countries, the United States is an important exception. In this subsection, I will show in a two-country example that allowing a country to set residence-based corporate taxes does not substantially improve its welfare. In particular, I consider $N = 2$ with $\gamma_{i\ell} = \tau_{\ell n} = 1.2$ for all $i \neq \ell$ and $\ell \neq n$, $A_i = T_i = \bar{L}_i = 1$ for $i = 1, 2$, $\theta = \sigma = 4$, $\epsilon = 6$, and $\tilde{\eta} = \infty$. I consider the optimal tax rates of country 1. In addition to $(\tilde{\kappa}_{11}, \tilde{\kappa}_{21})$, country 1 can also levy a tax on the profits of its MNE affiliates in country 2, $\tilde{\iota}_{12}$. I assume that there is no profit shifting for this new tax. This tax is therefore equivalent to a cost shifter of MNEs originated from country 1, defined as $\iota_{12} = (1 - \tilde{\iota}_{12})^{\frac{1}{1-\sigma}}$. Then for $i \neq \ell$, $\kappa_{i\ell}$ in Equation (12), (13) and (14) are replaced by $\kappa_{i\ell}\iota_{i\ell}$. The tax revenue is given by

$$\Lambda_\ell = \sum_{i,n} \frac{1}{\sigma} \tilde{\kappa}_{i\ell} X_{i\ell n} + \sum_{k,n} \frac{1}{\sigma} \left(1 - \tilde{\kappa}_{\ell k}\right) \tilde{\iota}_{\ell k} X_{\ell k n}. \tag{94}$$

The optimal corporate tax rates of country 1 is solved as $(\tilde{\kappa}^*_{11}, \tilde{\kappa}^*_{21}, \tilde{\iota}^*_{12}) = (0.07, 0.51, 0.064)$. It turns out that the optimal tax rate for the MNE affiliates abroad is very close to the optimal tax rate for domestic affiliates since these two taxes have similar effects on promoting firm entry. The optimal tax rates increase country 1's welfare by 2.05% relative to tax-free equilibrium. If I impose that $\tilde{\iota}_{12}^* = 0$, then the optimal source-based corporate tax rates are $(\tilde{\kappa}_{11}^*, \tilde{\kappa}_{21}^*) = (0.08, 0.51)$, which increase country 1's welfare by 2.03% relative to tax-free equilibrium. This example suggests that allowing residence-based corporate taxes does not considerably change our understanding to countries' motives to manipulate their corporate taxes.

# Appendix B Empirics and Quantification

## B.1 Data

In this subsection, I describe the data used in Section 4.4.

Corporate tax rates across 28 countries come from three sources. The local corporate tax rates in 2007 come from the PwC Global Effective Tax Rates (2011). It computes the effective corporate tax rates, defined as total income taxes divided by pretax income, for 59 countries based on the S&P Global Vantage database. To provide comparability of effective corporate tax rates across countries, a series of data cleaning processes have been implemented. For countries that are not covered by or have only few firms in the PwC Global Effective Tax Rates, I take the statutory local corporate tax rates from KPMG Corporate and Indirect Tax Rate Survey (2008). Table B.1 compares the effective local corporate tax rates with the statutory tax rates. These two tax rates are highly correlated (correlation = 0.75).

Table B.1: Effective and Statutory Corporate Tax Rates in 2007

| | Effective | Statutory | | Effective | Statutory |
|---|---|---|---|---|---|
| AUS | 0.27 | 0.30 | IND | 0.34 | 0.34 |
| AUT | 0.20 | 0.25 | IRL | 0.13 | 0.13 |
| BEL | 0.34 | 0.34 | ITA | 0.29 | 0.37 |
| BRA | 0.34 | 0.34 | JPN | 0.40 | 0.41 |
| CAN | 0.22 | 0.36 | KOR | 0.24 | 0.28 |
| CHN | 0.33 | 0.33 | MEX | 0.27 | 0.28 |
| DEU | 0.28 | 0.38 | NLD | 0.19 | 0.26 |
| ESP | 0.22 | 0.33 | POL | 0.19 | 0.19 |
| FIN | 0.26 | 0.26 | PRT | 0.27 | 0.27 |
| FRA | 0.23 | 0.34 | RUS | 0.26 | 0.24 |
| GBR | 0.24 | 0.30 | SWE | 0.22 | 0.28 |
| GRC | 0.25 | 0.25 | TUR | 0.20 | 0.20 |
| HUN | 0.14 | 0.16 | TWN | 0.14 | 0.25 |
| IDN | 0.28 | 0.30 | USA | 0.28 | 0.39 |

The statutory NRDW tax rates come from Huizinga, Voget, and Wagner (2014). Their data can be downloaded from https://www.aeaweb.org/articles?id=10.1257/pol.6.2.94. They describe their data sources in details in Table A1.

The bilateral MP flows in 2007 are imputed by the bilateral FDI stocks from the UNCTAD Database. The UNCTAD database provides bilateral FDI stocks, $X_{i\ell}^{\text{FDI}}$ for all $i \neq \ell$. I combine the UNCTAD database with the data on total capital stocks from Penn World Table 9.0 and compute $X_{\ell\ell}^{\text{FDI}} = X_{\ell}^{\text{Capital}} - \sum_{i\neq\ell} X_{i\ell}^{\text{FDI}}$. Then I compute the bilateral MP shares by assuming that $\frac{X_{i\ell}^{MP}}{\sum_k X_{k\ell}^{MP}} = \frac{X_{i\ell}^{FDI}}{\sum_k X_{k\ell}^{FDI}}$. Ramondo et al. (2015) has suggested that the bilateral FDI flows are highly correlated with the bilateral MP flows.

The bilateral trade flows (including domestic sales) in 2007 come from the World Input-Output database: http://www.wiod.org/database/wiots16. Notably, the current account balance implies that $\sum_k X_{k\ell}^{MP} = \sum_n X_{\ell n}^{TR}$ which completes the imputation of $X_{i\ell}^{MP}$.

## B.2 Robustness Checks for the Empirical Evidence

In this subsection, I conduct robustness tests for the reduced-form results in Section 4.3. In particular, I estimate Equation (29) using alternative data sources for MP sales and corporate tax rates. First, I regress the bilateral MP sales in 2001 from Ramondo et al. (2015) on the statutory corporate tax rates in 2001 from Huizinga, Voget, and Wagner (2014). Second, I regress the bilateral MP sales in 2007 constructed in Section B.1 on the statutory corporate tax rates in 2007 from KPMG Corporate and Indirect Tax Rate Survey (2008).

Table B.2: Bilateral MP sales and corporate tax rates

| | Year 2001 | Year 2007 | |
|---|---|---|---|
| | $i \neq \ell$ | All | $i \neq \ell$ |
| $\log(1-\tilde{\kappa}_{i\ell})$ | 2.327*** | 2.67** | 3.19*** |
| | (.83) | (1.06) | (.55) |
| $\mathbf{1}\{\text{Dist} \in [1000 \text{ km}, 11000 \text{ km}]\}$ | -.71*** | -2.218*** | -.858*** |
| | (.12) | (.26) | (.11) |
| $\mathbf{1}\{\text{Dist} > 11000 \text{ km}\}$ | -1.64*** | -3.067*** | -1.332*** |
| | (.44) | (.34) | (.15) |
| Contiguity | .76*** | -.593** | .75*** |
| | (.17) | (.25) | (.14) |
| Common language | .31** | 1.92*** | .55*** |
| | (.15) | (.28) | (.18) |
| Common legal origin | .88*** | .69*** | .47*** |
| | (.11) | (.12) | (.088) |
| Source/host fixed effects | ✓ | ✓ | ✓ |
| $R^2$ | .998 | .98 | .991 |
| # Obs. | 678 | 784 | 756 |

## B.3 Imputing "true" bilateral MP flows

Given $\tilde{\eta}$, the observed bilateral MP flows, $\tilde{X}_{i\ell}^{MP}$ can be expressed in terms of "true" bilateral MP flows, $X_{i\ell}^{MP}$, by Equation (32). Then I have

$$X_{i\ell}^{MP} = \tilde{X}_{i\ell}^{MP} + \sum_k \frac{1}{\sigma} \max\left\{\frac{\tilde{\kappa}_{i\ell} - \tilde{\kappa}_{ik}}{\tilde{\eta}/\lambda_{ik}^{MP}}, 0\right\} X_{i\ell}^{MP} - \sum_k \frac{1}{\sigma} \max\left\{\frac{\tilde{\kappa}_{ik} - \tilde{\kappa}_{i\ell}}{\tilde{\eta}/\lambda_{i\ell}^{MP}}, 0\right\} X_{ik}^{MP}. \tag{95}$$

Therefore, with an initial guess $\left(X_{i\ell}^{MP}\right)^{(0)}$, I compute the updated $\left(X_{i\ell}^{MP}\right)^{(1)}$ by the right-hand side of Equation (95). I repeatedly update $\left(X_{i\ell}^{MP}\right)^{(t)}$ until $\left(X_{i\ell}^{MP}\right)^{(t)} = \left(X_{i\ell}^{MP}\right)^{(t+1)}$. A problem of this iteration is that when the last term on the right-hand side of Equation (95) is large there would be negative values for $X_{i\ell}^{MP}$. In practice, I assume that the observed bilateral MP flows do not include the profits shifting in the country. This assumption is plausible since the observed bilateral MP flows come from UNCTAD data on bilateral FDI stocks. Without the last term on the right-hand side of Equation (95), I get strictly positive $X_{i\ell}^{MP}$ for all $(i, \ell)$.

## B.4 Imputing "tri-lateral" trade flows

In this section, I aim to express "tri-lateral" trade flows, $(X_{i\ell n})$, in terms of $\left(\tilde{T}_{i\ell}, \tau_{in}, \kappa_{i\ell}\right)$ and $(\epsilon, \rho, \sigma, \theta)$. First, for $i \neq \ell$

$$\zeta_{i\ell n} = \frac{\left[\sum_{k\neq i}\left(\tilde{T}_{ik}\tau_{kn}\kappa_{ik}\right)^{-\frac{\epsilon}{1-\rho}}\right]^{1-\rho}}{\left[\sum_{k\neq i}\left(\tilde{T}_{ik}\tau_{kn}\kappa_{ik}\right)^{-\frac{\epsilon}{1-\rho}}\right]^{1-\rho} + \left(\tilde{T}_{ii}\tau_{in}\kappa_{ii}\right)^{-\epsilon}} \times \frac{\left(\tilde{T}_{i\ell}\tau_{\ell n}\kappa_{i\ell}\right)^{-\frac{\epsilon}{1-\rho}}}{\sum_{k\neq i}\left(\tilde{T}_{ik}\tau_{kn}\kappa_{ik}\right)^{-\frac{\epsilon}{1-\rho}}}. \tag{96}$$

And

$$\zeta_{iin} = \frac{\left(\tilde{T}_{ii}\tau_{in}\kappa_{ii}\right)^{-\epsilon}}{\left[\sum_{k\neq i}\left(\tilde{T}_{ik}\tau_{kn}\kappa_{ik}\right)^{-\frac{\epsilon}{1-\rho}}\right]^{1-\rho} + \left(\tilde{T}_{ii}\tau_{in}\kappa_{ii}\right)^{-\epsilon}}. \tag{97}$$

Second, for $i \neq \ell$

$$\psi_{i\ell n} = \frac{\left[\sum_{k\neq i}\left(\tilde{T}_{ik}\tau_{kn}\kappa_{ik}\right)^{-\frac{\epsilon}{1-\rho}}\right]^{-\rho}\left(\tilde{T}_{i\ell}\tau_{\ell n}\kappa_{i\ell}\right)^{-\frac{\epsilon}{1-\rho}}\kappa_{i\ell}^{\sigma-1}}{\left[\sum_{k\neq i}\left(\tilde{T}_{ik}\tau_{kn}\kappa_{ik}\right)^{-\frac{\epsilon}{1-\rho}}\right]^{-\rho}\sum_{k\neq i}\left(\tilde{T}_{ik}\tau_{kn}\kappa_{ik}\right)^{-\frac{\epsilon}{1-\rho}}\kappa_{ik}^{\sigma-1} + \left(\tilde{T}_{ii}\tau_{in}\kappa_{ii}\right)^{-\epsilon}\kappa_{ii}^{\sigma-1}}. \tag{98}$$

And

$$\psi_{iin} = \frac{\left(\tilde{T}_{ii}\tau_{in}\kappa_{ii}\right)^{-\epsilon}\kappa_{ii}^{\sigma-1}}{\left[\sum_{k\neq i}\left(\tilde{T}_{ik}\tau_{kn}\kappa_{ik}\right)^{-\frac{\epsilon}{1-\rho}}\right]^{-\rho}\sum_{k\neq i}\left(\tilde{T}_{ik}\tau_{kn}\kappa_{ik}\right)^{-\frac{\epsilon}{1-\rho}}\kappa_{ik}^{\sigma-1}+\left(\tilde{T}_{ii}\tau_{in}\kappa_{ii}\right)^{-\epsilon}\kappa_{ii}^{\sigma-1}}. \tag{99}$$

Third,

$$(M_iT_i)^{-\frac{1}{\theta}}\,\Phi_{in} = \left\{\left[\sum_{k\neq i}\left(\tilde{T}_{ik}\tau_{kn}\kappa_{ik}\right)^{-\frac{\epsilon}{1-\rho}}\right]^{1-\rho}+\left(\tilde{T}_{ii}\tau_{in}\kappa_{ii}\right)^{-\epsilon}\right\}^{-\frac{1}{\epsilon}}. \tag{100}$$

Then,

$$\Psi_{in} = \sum_{k=1}^{N}\zeta_{ikn}\kappa_{ik}^{\sigma-1} = \frac{\left[\sum_{k\neq i}\left(\tilde{T}_{ik}\tau_{kn}\kappa_{ik}\right)^{-\frac{\epsilon}{1-\rho}}\right]^{-\rho}\sum_{k\neq i}\left(\tilde{T}_{ik}\tau_{kn}\kappa_{ik}\right)^{-\frac{\epsilon}{1-\rho}}\kappa_{ik}^{\sigma-1}+\left(\tilde{T}_{ii}\tau_{in}\kappa_{ii}\right)^{-\epsilon}\kappa_{ii}^{\sigma-1}}{\left[\sum_{k\neq i}\left(\tilde{T}_{ik}\tau_{kn}\kappa_{ik}\right)^{-\frac{\epsilon}{1-\rho}}\right]^{1-\rho}+\left(\tilde{T}_{ii}\tau_{in}\kappa_{ii}\right)^{-\epsilon}}. \tag{101}$$

Then, for $i\neq\ell$,

$$\frac{X_{i\ell n}}{X_n} = \left[\sum_{k\neq i}\left(\tilde{T}_{ik}\tau_{kn}\kappa_{ik}\right)^{-\frac{\epsilon}{1-\rho}}\right]^{-\rho}\left(\tilde{T}_{i\ell}\tau_{\ell n}\kappa_{i\ell}\right)^{-\frac{\epsilon}{1-\rho}}\kappa_{i\ell}^{\sigma-1}\times$$
$$\frac{\left\{\left[\sum_{k\neq i}\left(\tilde{T}_{ik}\tau_{kn}\kappa_{ik}\right)^{-\frac{\epsilon}{1-\rho}}\right]^{1-\rho}+\left(\tilde{T}_{ii}\tau_{in}\kappa_{ii}\right)^{-\epsilon}\right\}^{\frac{\theta}{\epsilon}-1}}{\sum_{h=1}^{N}\left\{\left[\sum_{k\neq h}\left(\tilde{T}_{hk}\tau_{kn}\kappa_{hk}\right)^{-\frac{\epsilon}{1-\rho}}\right]^{1-\rho}+\left(\tilde{T}_{hh}\tau_{hn}\kappa_{hh}\right)^{-\epsilon}\right\}^{\frac{\theta}{\epsilon}-1}\left\{\left[\sum_{k\neq h}\left(\tilde{T}_{hk}\tau_{kn}\kappa_{hk}\right)^{-\frac{\epsilon}{1-\rho}}\right]^{-\rho}\sum_{k\neq h}\left(\tilde{T}_{hk}\tau_{kn}\kappa_{hk}\right)^{-\frac{\epsilon}{1-\rho}}\kappa_{hk}^{\sigma-1}+\left(\tilde{T}_{hh}\tau_{hn}\kappa_{hh}\right)^{-\epsilon}\kappa_{hh}^{\sigma-1}\right\}}. \tag{102}$$

And

$$\frac{X_{iin}}{X_n} = \left(\tilde{T}_{ii}\tau_{in}\kappa_{ii}\right)^{-\epsilon}\kappa_{ii}^{\sigma-1}\times$$
$$\frac{\left\{\left[\sum_{k\neq i}\left(\tilde{T}_{ik}\tau_{kn}\kappa_{ik}\right)^{-\frac{\epsilon}{1-\rho}}\right]^{1-\rho}+\left(\tilde{T}_{ii}\tau_{in}\kappa_{ii}\right)^{-\epsilon}\right\}^{\frac{\theta}{\epsilon}-1}}{\sum_{h=1}^{N}\left\{\left[\sum_{k\neq h}\left(\tilde{T}_{hk}\tau_{kn}\kappa_{hk}\right)^{-\frac{\epsilon}{1-\rho}}\right]^{1-\rho}+\left(\tilde{T}_{hh}\tau_{hn}\kappa_{hh}\right)^{-\epsilon}\right\}^{\frac{\theta}{\epsilon}-1}\left\{\left[\sum_{k\neq h}\left(\tilde{T}_{hk}\tau_{kn}\kappa_{hk}\right)^{-\frac{\epsilon}{1-\rho}}\right]^{-\rho}\sum_{k\neq h}\left(\tilde{T}_{hk}\tau_{kn}\kappa_{hk}\right)^{-\frac{\epsilon}{1-\rho}}\kappa_{hk}^{\sigma-1}+\left(\tilde{T}_{hh}\tau_{hn}\kappa_{hh}\right)^{-\epsilon}\kappa_{hh}^{\sigma-1}\right\}}. \tag{103}$$

Given $(\epsilon,\rho,\theta,\rho,\kappa_{i\ell})$, I can solve $(\tilde{T}_{i\ell},\tau_{\ell n})$ targeting on $(X_{i\ell}^{MP},X_{\ell n}^{TR})$. Notice that the "true" bilateral MP flows $X_{i\ell}^{MP}$ are imputed from the observed bilateral MP flows $\tilde{X}_{i\ell}^{MP}$ in Section 4.4.

## B.5 System of Equations for Unilaterally Optimal Tax

The unilaterally optimal corporate tax for country 1 is solved from the following constrained optimization problem:

$$\max_{\hat{W}_\ell, \kappa'_{i1}, \left\{\left(\lambda_{ik}^{MP}\right)', \hat{w}_i^p, \hat{w}_i^e, \hat{X}_i, \hat{P}_i, \hat{M}_i, \hat{L}_i^p\right\},} \hat{W}_\ell,$$

s.t. $\forall i$

$$\begin{aligned}
e_i^1 &= \left[\left(1-\frac{1}{\sigma}\right)\sum_{k,n} X'_{kin} + \delta \sum_{k=1}^{N} \frac{X'_{ki}}{\Psi'_{ki}}\right] - \hat{w}_i^p \hat{L}_i^p w_i^p L_i^p = 0 \\
e_i^2 &= \left[\hat{w}_i^p \hat{L}_i^p w_i^p L_i^p + \hat{w}_i^e \hat{M}_i w_i^e L_i^e + \Lambda'_i\right] - \hat{X}_i X_i = 0 \\
e_i^3 &= \sum_{\ell,n}\left[\frac{1}{\sigma}\left(\kappa'_{i\ell}\right)^{1-\sigma} X'_{i\ell n} - \delta \zeta'_{i\ell n} \frac{X'_{in}}{\Psi'_{in}}\right] - \hat{w}_i^e \hat{M}_i M_i w_i^e f^e = 0 \\
e_i^4 &= \left(\frac{\hat{w}_i^e}{\hat{Y}_i}\right)^{\kappa-1} - \hat{M}_i = 0, \quad \hat{Y}_i = \hat{w}_i^e \hat{L}_i^e \frac{w_i^e L_i^e}{Y_i} + \hat{w}_i^p \hat{L}_i^p \frac{w_i^p L_i^p}{Y_i}., \\
e_i^5 &= \left(\frac{\hat{w}_i^p}{\hat{Y}_i}\right)^{\kappa-1} - \hat{L}_i^p = 0, \\
e_n^6 &= \left[\left(\frac{\hat{w}_n^p}{\hat{X}_n}\right)^{-\frac{\theta-(\sigma-1)}{\sigma-1}} \left\{\sum_{i=1}^{N} \lambda_{in} \hat{M}_i \hat{\Phi}_{in}^{-\theta} \hat{\Psi}_{in}\right\}\right] - \hat{P}_n^{-\theta} = 0, \\
e_{i\ell}^7 &= \left\{1 - \tilde{\kappa}'_{i\ell} + \sum_{k=1}^{N}\left[\left(\tilde{\kappa}'_{i\ell} - \tilde{\kappa}'_{ik}\right)\max\left\{\frac{\tilde{\kappa}'_{i\ell} - \tilde{\kappa}'_{ik}}{\tilde{\eta}/\left(\lambda_{ik}^{MP}\right)'}, 0\right\} - \frac{1}{2}\frac{\tilde{\eta}}{\left(\lambda_{ik}^{MP}\right)'}\max\left\{\frac{\tilde{\kappa}'_{i\ell} - \tilde{\kappa}'_{ik}}{\tilde{\eta}/\left(\lambda_{ik}^{MP}\right)'}, 0\right\}^2\right]\right\}^{\frac{1}{1-\sigma}} - \hat{\kappa}_{i\ell}\kappa_{i\ell}, \\
e_i^8 &= \frac{\sum_n X'_{i\ell n}}{\sum_{k,n} X'_{ikn}} - \left(\lambda_{i\ell}^{MP}\right)' = 0, \\
e_i^9 &= \frac{\hat{X}_i}{\hat{P}_i} - \hat{W}_i = 0.
\end{aligned} \tag{104}$$

The Jacobian matrix for the objective function is simple: $\frac{\partial \hat{U}_\ell}{\partial \hat{U}_\ell} = 1$ and all other elements are 0.

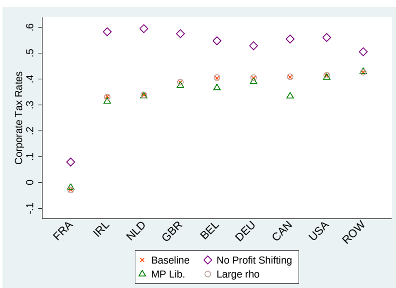
## B.6 Sensitivity of Nash and Cooperative Corporate Taxes

I compute Nash taxes under alternative parameter values. The results are illustrated by Figure B.1. It shows that without profit shifting, Nash corporate tax rates for foreign firms would be much higher, leading to larger welfare losses for participation countries. Having lower MP costs or larger $\rho$ do not affect Nash taxes very much.

(a) Belgium

(b) Canada

(c) Germany



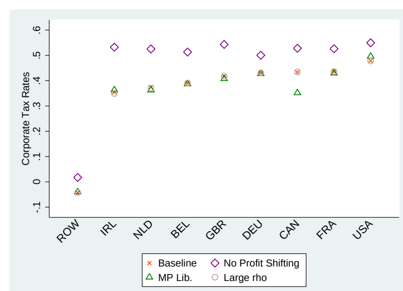
(d) France

(e) U.K.

(f) Ireland

(g) The Netherlands

(h) U.S.

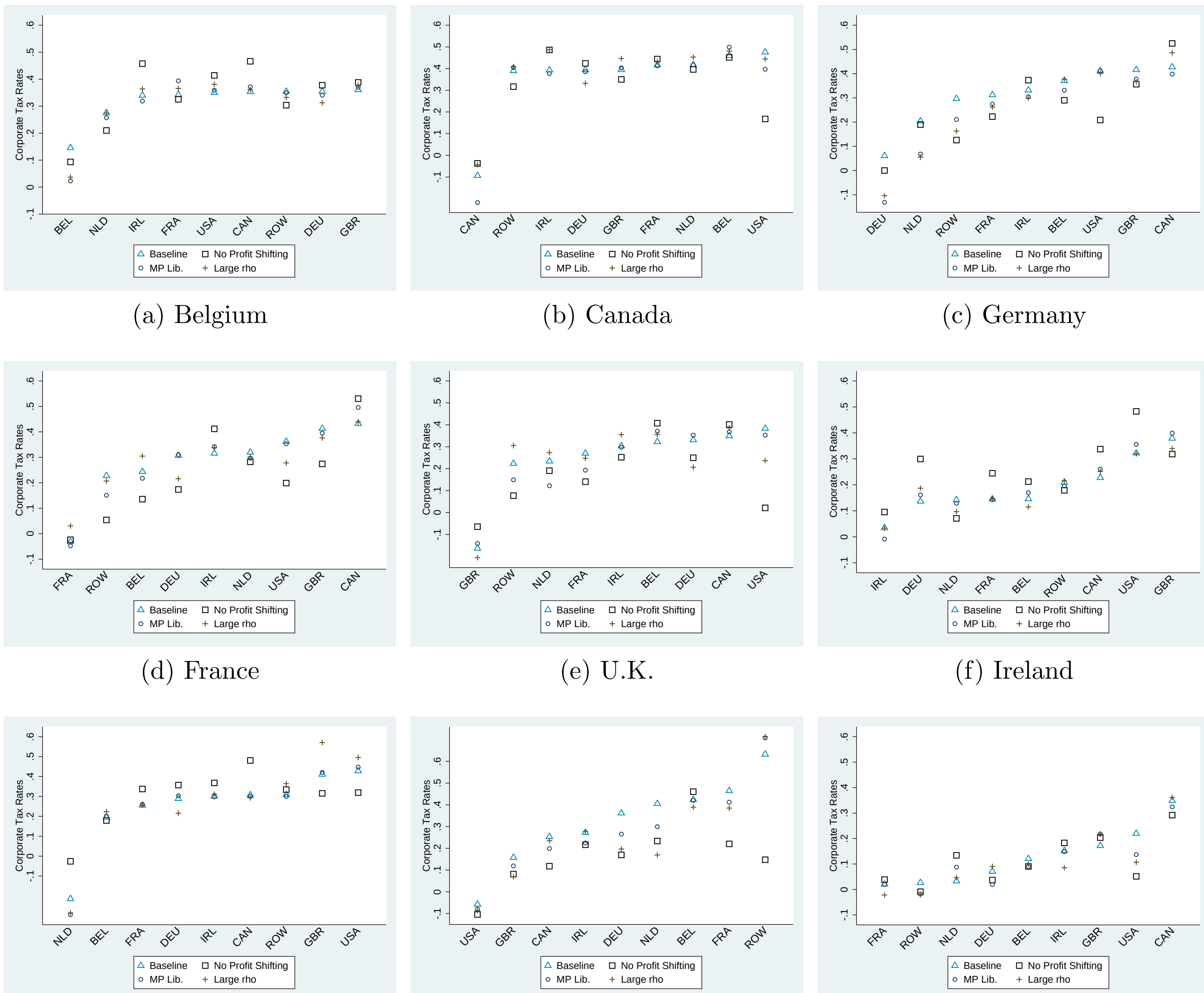


(i) ROW

Figure B.1: Nash Corporate Taxes: Sensitivity

(Note: No profit shifting refers to the case where $\tilde{\eta} = \infty$. MP liberalization refers to the case where $\gamma_{i\ell}$ decrease by 10% for all $i \neq \ell$. Larger $\rho$ refers to the case where $\rho = 0.5$.)

I also compute cooperative taxes under alternative parameter values. The results are illustrated by Figure B.2. Having larger $\rho$ results in lower cooperative tax rates since MNEs are more footloose in deciding their foreign production sites.




(a) Belgium (b) Canada (c) Germany

(d) France (e) U.K. (f) Ireland

(g) The Netherlands (h) U.S. (i) ROW

Figure B.2: Cooperative Corporate Taxes: Sensitivity

(Note: No profit shifting refers to the case where $\tilde{\eta} = \infty$. MP liberalization refers to the case where $\gamma_{i\ell}$ decrease by 10% for all $i \neq \ell$. Larger $\rho$ refers to the case where $\rho = 0.5$.)

## B.7 Optimal Taxes with Residence-Based Taxation

In Section A.6, I have shown in a two-country example that allowing residence-based taxation does not considerably affect welfare gains from optimal taxation. In this subsection, I will compute the U.S. optimal corporate taxes that include residence-based taxes. I consider a world with eight countries and the rest of the world discussed in Section 6.2. The residence-based corporate taxes, $\tilde{\iota}_{i\ell}$, are collected by the source country $i$. I assume that initially there is no residence-based taxation. Moreover, I omit the profit shifting of the residence-based taxes. Then $\tilde{\iota}_{i\ell}$ is equivalent to a cost shifter defined as $\iota_{i\ell} = (1 - \tilde{\iota}_{i\ell})^{\frac{1}{1-\sigma}}$ in determining firms' production sites. Then $\hat{\kappa}_{i\ell}$ in the "exact-hat" algebra is replaced by $\hat{\kappa}_{i\ell}\hat{\iota}_{i\ell}$. The additional tax revenues are computed accordingly.

Table B.3 shows the U.S. optimal corporate tax rates with and without residence-based taxes. The results suggest that the optimal tax rates on foreign-source income are much smaller in absolute values than the U.S. optimal NRDW tax rates. Moreover, allowing for residence-based taxation does not change the optimal local corporate tax rate very much. Finally, the U.S. welfare gain from optimal taxes without residence-based taxation is 1.7283%, whereas the U.S. welfare gain from optimal taxes with residence-based taxation is 1.7373%. Consistent with the two-country example in Section A.6, I find that the residence-based taxation has very little impacts on my quantitative analysis on optimal corporate taxes.

Table B.3: Optimal Corporate Tax Rates in the U.S. with Residence-Based Taxes

| | No Residence-Based | With Residence-Based | |
|---|---|---|---|
| | $\tilde{\kappa}_{i\ell}$ | $\tilde{\kappa}_{i\ell}$ | $\tilde{\iota}_{i\ell}$ |
| Belgium | 0.3575 | 0.3558 | -0.1660 |
| Canada | 0.4335 | 0.4306 | 0.0839 |
| Germany | 0.3658 | 0.3640 | -0.0222 |
| France | 0.3801 | 0.3785 | -0.0044 |
| U.K. | 0.3770 | 0.3758 | 0.1005 |
| Ireland | 0.3350 | 0.3327 | -0.0992 |
| The Netherlands | 0.3742 | 0.3726 | -0.0633 |
| U.S. | -0.0111 | -0.0198 | 0 |
| ROW | 0.3760 | 0.3739 | -0.0382 |