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Does e-commerce ease or intensify tax competition? Destination principle versus origin principle

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Abstract
This study examines the relationship between e-commerce development and the intensity of commodity tax competition under two tax principles for goods purchased online: the destination principle and the origin principle. The main findings are as follows: Given that origin-based tax is applied to purchases made in brick-and-mortar stores, (i) tax competition under destination-based taxation on e-commerce is more intense than tax competition under origin-based taxation; and (ii) the expansion of the online market intensifies destination-based tax competition while easing origin-based tax competition. The main factor leading to the results is that replacing the choice of "where to purchase" goods, consumers will have a new choice of "how to purchase" when online purchasing becomes available, and destination-based taxation distorts the latter choice, while origin-based taxation is neutral.

Keywords Tax competition · E-commerce · Tax principles

JEL Classification H21 · H71 · H87

1 Introduction

The development of e-commerce and the associated change in the role of consumption taxes have recently led theoretical researchers to study e-commerce taxation (Bacache-Beauvallet, 2018; Agrawal and Wildasin, 2020). Underlying this is the policy concern that failing to design an adequate tax system for expanding

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e-commerce will create significant tax revenue losses, as e-commerce could trigger increased tax competition and more channels for tax avoidance.[1] Specifically, the ability to purchase goods and services via the Internet allows consumers to choose the region from which to purchase, not only from neighboring regions but also from more distant regions and, therefore, from a greater number of regions. This would accelerate the interregional commodity tax competition for cross-border consumption. Our study intends to present one view of this new field of research, which searches for an appropriate way to tax e-commerce transactions. Specifically, our study provides one possible answer to the question of whether the imposition of taxes on e-commerce should be based on origin or destination principles. In the case of taxation based on the former, tax is levied on transactions of goods and services at the supplier's location, and in the case of the latter, it is levied on the recipient of goods or services. VAT in the EU has experienced both of these tax principles. It was crafted about three decades ago, when e-commerce was almost non-existent, with the aim of arriving at a definitive VAT system based on the origin principle, but it has now shifted toward destination principle taxation. The result derived in this study is that taxing e-commerce under the origin principle rather than the destination principle will be superior from the standpoint of a revenue-maximizing government if, as we still observe in a number of cases, origin-based taxes are applied to the purchase of goods in brick-and-mortar stores.

Many classic studies on cross-border shopping that do not address e-commerce have analyzed the choice between origin and destination principles. There is a general consensus that the destination principle of taxation is superior to the origin principle of taxation when assuming a competitive market (Keen and Lahiri, 1998, p.325). Economists have recognized the importance of enforcing a destination-based tax to avoid inter-regional competition that lowers tax rates (Lockwood et al., 1994a, p.5; Agrawal and Fox, 2017, p.917). In the case of origin-based taxation, a region with a lower tax rate has an advantage in terms of the tax burden on mobile firms and consumers, leading to a race for lower taxes. However, in the case of destination-based taxation, even if tax rates differ among regions, the tax burden on them is the same regardless of where the production and consumption activities take place; thus, competition for lower taxes is avoided and efficiency is not impaired. Subsequent studies broadened the scope of analysis to include imperfectly competitive markets with factors such as trade costs, spillovers, and unemployment. Some studies have confirmed that the superiority of the destination principle holds true, whereas others have indicated the possibility of a counterview (Lockwood et al., 1995; Lockwood, 2001; Haufler and Pflüger, 2004; Haufler et al., 2005;

[1] There have been numerous estimates of the magnitude of tax revenue lost due to the growth of e-commerce. In the early stages, Bruce and Fox (2000) and Bruce et al. (2009) found that as of 1999, the US had lost $7 billion in annual state and local tax revenue due to e-commerce, and by 2012, that amount is estimated to increase to about $11.4 billion to $12.7 billion. In the most recent, Beem and Bruce (2021) showed that an increase in online firms could affect (and might slightly increase) tax revenues by changing the number of firms with sales tax liability.

Hashimzade et al., 2011; Antoniou et al., 2019, 2022; Agrawal and Mardan, 2019).[2] The contribution of our study in this context is to present a model that includes e-commerce, which was not included in the analysis of any of the various types of models mentioned above; however, such an analysis will inevitably be complicated by the addition of new purchase options to these models in which consumers only purchase goods in brick-and-mortar stores. To present our main findings with analytical solutions, we focus on the symmetric equilibrium in the majority of studies. The findings when asymmetry is included are presented in the Discussion section.

The most closely related theoretical study to our own, encompassing both e-commerce and taxation, pertains to Agrawal and Wildasin (2020). They extend commodity tax competition models with a specific focus on online purchases, subjecting them to destination-based taxation, whereas goods procured from brick-and-mortar stores are taxed in accordance with the principle of origin. Presenting a tractable model in which the number of Internet users is endogenously determined, they reveal that as the cost of online purchasing decreases and e-commerce expands, the tax rate decreases in the core region where special goods available for online purchases are produced. By contrast, the tax rate in the peripheral region increases, leading to a reduction in tax differentials.[3] Two empirical studies corroborate the findings of this research. Agrawal (2021) empirically clarified the relationship between the growth of online consumption and tax rates, providing evidence that higher Internet penetration generally results in diminished local tax rates, yet certain regions experience a rise in tax rates. Using the surge of e-commerce during the COVID-19 pandemic, Agrawal and Shybalkina (2023) demonstrated the negative impact of e-commerce growth on tax revenues in urban areas, whereas rural areas experienced a positive impact.

Agrawal and Wildasin (2020) share a common objective with our study: to elucidate equilibrium tax rates in this novel modality of conducting Internet transactions. Nevertheless, there are two salient distinctions between their study and ours that allow us to pursue different research inquiries. First, we extend the model of Agrawal and Wildasin (2020) by considering the imposition of an origin-based tax on purchases of goods and services via the Internet, in addition to a destination-based tax on e-commerce. Second, we relax the restrictive assumption posited by Agrawal and Wildasin (2020) to construct a model that accommodates a more comprehensive demand structure.

[2] See also Lockwood et al. (1994a, 1994b) and Genser (1996) for studies that identify the conditions under which the two tax principles could be equivalent. They point to the importance of adjustments in wages and exchange rates and show that the two tax principles are equivalent when wages and exchange rates are freely adjusted; a shift from the destination principle to the origin principle could cause real prices to adjust so that changes in wages and exchange rates offset the effects of the change in tax principle.

[3] Other related studies are Bacache-Beauvallet (2018) and Birg (2019). The former develops a model of taxation on e-commerce with fixed number of Internet users to show that large regions prefer the destination principle for e-commerce, whereas small regions prefer the origin principle. The latter shows that a destination- (orgin-) based tax on online purchases weakens (strengthens) tax competition, assuming a case in which brick-and-mortar stores are located on the edge of the line economy based on Aiura and Ogawa (2013), and online retail stores are located in either region.

On the first point, as Agrawal and Fox (2017, 2021) noted, there is an international trend toward destination-based taxation of goods purchased online. This trend can be seen in the legal changes in the taxation rules for e-commerce across the US. In 1992, the US Supreme Court's decision in Quill Corp. v. North Dakota prohibited state governments from collecting taxes from retail purchases made via the Internet or other e-commerce channels unless the seller had physical establishments in the state. However, the recent case of South Dakota v. Wayfair Inc. in 2018 overturned the decision of Quill on the grounds that it was "unsound and incorrect" in the current age of Internet services, providing a legal basis for taxation under the destination principle.[4] The policy trend is toward the destination principle, but it would not be appropriate to leave the applicability of origin-based taxation to e-commerce out of the analysis altogether, as origin-based taxation is less costly from a practical point of view (OECD, 2001, p.16). Therefore, emerging economies are exploring the implementation of origin-based taxes in e-commerce.[5] Examples of the (quasi-) origin principle taxation of e-commerce in developed countries are also provided. Since 2015, the tax rate of the country in which the consumer resides has been applied to e-commerce services in Europe; however, the application of such a destination principle tax involves accounting checks and controls compliance costs. Therefore, only sellers with sales above a certain level are subject to destination taxes, whereas the origin principle tax is applied to electronic transaction services sold by many other small businesses (Bacache-Beauvallet, 2018, p.101). Even in the US, where the destination principle governs the taxation of e-commerce, certain states have implemented a system wherein intrastate e-commerce sales are attributed to the region of origin (Agrawal and Shybalkina, 2023, p.9). These instances illustrate that when levying taxes on e-commerce, a combination of destination- and origin-based taxes is employed, at least in part, raising the question of which tax principles should be prioritized.

Second, we attempt to extend and contribute to the field by generalizing the analytical framework to align with the results of empirical studies. According to Agrawal and Wildasin (2020), consumers demand all goods inelastically regardless of how the tax-price changes. While this assumption might be acceptable for certain goods, it is difficult to apply to many other goods and services in online retail markets.[6] Empirical studies, in particular, exhibit a proclivity to diverge from the

[4] Studies have just begun to measure the impact of changes in taxation principles on tax revenues. For instance, Fox et al. (2022) showed that the 2018 ruling increased sales tax revenue by 7.9% using state-level data.

[5] In 2014, there was a case in Brazil where the Supreme Court ruled on the application of the origin principle taxation by the government on the Brazilian value-added tax called ICMS (Imposto sobre Circulação de Mercadorias e Serviços de Tranporte Intermunicipal, Interstadual e de Comunicação) on interstate electronic transactions. Gutuza (2010) studied how the source, or origin, principle can be applied to e-commerce firms operated through the use of a server in which physical presence is not required and argues that origin-based taxation remains an important consideration even though South Africa is moving to a residential basis of taxation.

[6] Some previous studies, e.g., Devereux et al. (2007), Agrawal (2016), and Aiura and Ogawa (2019), that have limited their focus to the case of purchasing goods in brick-and-mortar stores have relaxed the assumption of inelastic demand, but none of them have included e-commerce in their analysis.

assumptions made in theoretical models. Goolsbee (2000) utilized data on the US Internet sales from 1997 to 1998 and revealed that prevailing sales taxes on online purchases could potentially reduce the number of online buyers by up to 24%. Einav et al. (2014) found that a one-percentage-point increase in state sales taxes leads to a 2% increase in online purchases and a 3–4% decline in purchases from brick-and-mortar retail stores. Ellison and Ellison (2009) also found a negative relationship between e-retail sales and sales tax. Other studies estimated the tax elasticity of Internet shopping, with elasticities spanning from 0.2 to 0.5 (Alm and Melnik, 2005; Ballard and Lee, 2007).[7] Drawing on the findings of these empirical studies, we construct a model with a more comprehensive demand structure for e-commerce, thereby accommodating elastic goods. This generalization of the demand structure affords consumers the flexibility to decide "how much to buy" and "how to buy" the goods.[8]

By considering these new elements under the assumption that origin-based taxes are imposed on the purchases of goods in brick-and-mortar stores, we obtain the following results: First, for any given online purchase cost, the tax rates and revenues under origin-based tax competition are higher than those under destination-based tax competition. This is because the tax response of a region to tax changes in other regions is smaller when an origin-based tax is applied to e-commerce than when a destination-based tax is applied, meaning that origin-based tax competition is less intense. This makes the origin-based tax on e-commerce superior to the destination-based taxation in terms of smaller deviations from the coordinated tax rate that maximizes the sum of all regional tax revenues. Second, the expansion of the online market, expressed by lower online purchase costs, increases equilibrium tax rates and tax revenues under origin-based tax competition and decreases them under destination-based tax competition. This suggests that the expansion of the online market intensifies destination-based tax competition while easing origin-based tax competition. These results are derived using a model in which consumers purchase two different goods and have elastic demand, which is a more generalized version of that of Agrawal and Wildasin (2020). In our model, with each region having a different history, culture, climate, resources, etc., competitive firms operating in region x produce good x, whereas competitive firms in another region y produce good y, which is differentiated from good x. Because the goods produced in the two regions are different, consumers in region x with a preference for variety will buy not only good x produced in their own region but also good y produced in region y. In this case, consumers do not have a choice of where to buy goods from. Instead, consumers in region x, for example, will have a new choice on how to buy good y—that

[7] Furthermore, some studies suggest that the penetration of Internet purchases has led to higher tax elasticity of demand. Goolsbee et al. (2010) found that in areas with the highest Internet penetration, the sensitivity of cigarette demand to taxes is 69% higher. Smith and Brynjolfsson (2001) showed that Internet buyers are twice as sensitive to tax rate changes as they are to price changes.

[8] Bacache-Beauvallet (2018), who only has one type of good, also assumed inelastic demand. Another assumption in Agrawal and Wildasin (2020) is that the two goods are independent. We maintain this assumption to avoid complicating the analysis. However, Aiura and Ogawa (2021) showed that the results remain the same even when the two goods are not independent but substitutes.

is, whether to travel to a brick-and-mortar store in region y or buy it from stores in region y online. Excluding the choice of where to purchase is a device in the model that extracts the effect of a new choice of how to purchase.

Our finding that origin-based tax is superior to destination-based tax in terms of easing competition for lower tax rates and securing more tax revenue may be unexpected. However, given that we included e-commerce as a new way of making purchases, the mechanism leading to this result is simple. Destination-based taxation has been considered superior because it is neutral to the consumer's choice of where to buy goods. However, when a new means of purchasing goods online is added, in addition to purchasing goods in brick-and-mortar stores, consumers are given the option of how to buy them. Because the origin-based tax is applied to purchases made in brick-and-mortar stores, when consumers in region x purchase good y in stores in region y, the tax they pay is paid to region y and not received by the government in region x. However, if they purchase the same goods online from region y, the government in region x receives the tax they pay if a destination-based tax is applied to online purchases. Thus, governments have an incentive to shift consumers residing in their region from purchasing goods at brick-and-mortar stores to online purchases when destination-based taxes are imposed on online purchases, thus causing competition among governments for a tax base and creating fiscal externalities. If the origin principle of taxation is applied to online purchases in the same way as it is applied to purchases of goods in brick-and-mortar stores, the government loses the incentive to change the way consumers buy; the origin-based tax on e-commerce does not affect the consumer's choice of how to buy goods and is, therefore, neutral to the tax base.

The remainder of this paper is organized as follows: Sect. 2 introduces our model. In Sects. 3 and 4, we derive the symmetric equilibrium of tax competition when taxes are imposed at the origin and destination principles, respectively. By comparing the results of these two sections, we show the superiority of origin-based taxation in e-commerce. In Sect. 5, we present additional results obtained under the assumption of two regions with different population sizes. We also discuss the equilibrium when consumers have no choice in how to purchase, based on the special case in which they purchase exclusively online. Finally, Sect. 6 presents the conclusions of this study.

2 Model

2.1 Basic setup

We assume a model analogous to Hotelling (1929) line economy with two regions (Nielsen, 2001). Consumers and competitive firms are uniformly distributed in the line economy. The population in region i ($i = 0, 1$) is denoted by N_i. We assume $N_0 = 1 + b$ and $N_1 = 1 - b$ where $b \in [0, 1)$ is a constant. Each competitive firm located in either region has a permanent establishment (PE) upon which its taxation is predicated. Firms operating in region 0(1) produce good 0(1). They have retail outlets that cater to consumer demand, as well as to consumers who place orders online without visiting a store. Although it is possible for one region to produce both goods, we consider a scenario in which each region specializes in the production of a specific commodity to facilitate clearer outcomes. This framework enables the analysis to concentrate on consumer choices regarding how to make purchases, excluding the consideration of where to make purchases. Although the model is constructed to streamline the analysis, it reflects a scenario in which two goods with distinct characteristics based on the region of production are consumed.

All competitive firms operating in the same region are homogeneous, and their profits in equilibrium are zero.[9] Consumers choose to purchase each good either by visiting a brick-and-mortar store or online, along with the quantity purchased. When consumers purchase good i, they face the same price as p_i regardless of how they purchase it. The price of goods supplied by competitive firms in region i is equal to their marginal cost c_i. While prices may differ depending on the method of purchase, Cavallo (2017)'s survey of ten countries shows that for 72% of goods (69% in the US), the price of goods is the same for online and offline purchases. In particular, clothing and electronics are more likely to have the same price, regardless of the method of purchase. In our analysis, we assume goods for which there is no difference in price by method of purchase, or, if there is, the price gap remains reasonably small. In the following analysis, we assume that the marginal costs are the same in the two regions $c_i = c$.

In our theoretical framework, firms supply goods through two distinct channels: in-store sales and online sales. Consequently, the region in which firms with a PE are situated can enact taxation based on the origin principle, regardless of whether sales are made through in-store purchases or online transactions. Origin-based taxes are commonly applied to purchases made in brick-and-mortar stores, as exemplified by Kanbur and Keen (1993), Nielsen (2001), and Agrawal and Wildasin (2020). This approach arises because of the challenges governments face in effectively monitoring consumer purchases across cities or states and levying taxes on consumption in stores beyond their respective jurisdictions. Conversely, for sales conducted through online channels, a destination-based tax could be implemented. Indeed, there is a policy shift toward adopting destination-based taxation for e-commerce sales facilitated by firms lacking PE, as highlighted in Sect. 1. As such, we analyze a scenario in which the origin principle tax is applied to purchases made in brick-and-mortar stores, while either the origin or destination principle taxes are applied to online purchases.

Let s_{ij} denotes a cost other than the price of the good that a consumer in region i incurs when purchasing the goods produced in region j. The size of s_{ij} depends

[9] While we have included the behavior of oligopolistic firms with horizontally differentiated products in our discussion paper, that is, Aiura and Ogawa (2021), we develop a model here that discards firm behavior because similar results can be presented in a simpler way. Thus, we analyze situations in which goods are purchased through the Internet, either by ordering from competitive stores or by mail, rather than situations in which goods are purchased from a monopolistic multinational digital company such as Amazon.

on whether the consumer purchases goods in a brick-and-mortar store or online, as explained below:

Purchasing goods in brick-and-mortar stores. When residents of region i purchase goods produced in region i (their own region) from stores, the cost of purchasing per unit of the goods is $p_i + s_{ii}$, where $s_{ii} = t_i$. t_i is the unit tax rate imposed by the government in region i. Because the goods produced in region i are sold everywhere in region i, consumers can purchase goods without traveling. Consumers in region i also purchase good $j(\neq i)$ produced in region j. When they go to a neighboring region to buy good j from brick-and-mortar stores, the per-unit purchase cost is $p_j + s_{ij}$, where $s_{ij} = t_j + \delta x_{ij}$. δ and x_{ij} are the travel expense per distance and the travel distance from region i to region j. We assume that x_{ij} differs depending on where the consumers reside and is uniformly distributed in the interval $[0, N_i]$. Because the in-store purchase of goods is taxed based on the origin principle, consumers pay the tax imposed by the region in which the goods are supplied. We assume that the goods cannot be resold to exclude from the analysis the situation in which a consumer in region i living near the border buys goods in region j and resells them to a consumer in region i far from the regional border.

Purchasing goods online. When goods are purchased online, governments impose a tax on them based on either the origin or destination principle. First, if a consumer in region i purchases a good in region $j(\neq i)$ online, the per-unit cost of purchasing it is $p_j + s_{ij}$, where $s_{ij} = t_j + e$ if it is taxed under the origin principle. Here, $e(> 0)$ is the common cost in any region associated with purchasing the good online. When purchasing goods online, the cost of traveling to a store is not an important factor. Instead, consumers bear certain costs for shipping and costs associated with the risk of purchasing goods that are different from those they had imagined because they do not see the actual goods in stores before purchasing them online. These are represented by cost e, which is independent of the place of residence.[10] A situation where goods could not be purchased through e-commerce, as was the case a few decades ago, corresponds to a sufficiently large value of e. Second, when goods are taxed under the destination principle, regardless of where the goods are supplied, the tax rate in the place of residence applies, so consumers in region i bear the cost of $p_j + s_{ij}$, where $s_{ij} = t_i + e$. Finally, the cost of online purchase of a domestically produced good by a consumer in region i is $p_i + s_{ii}$, where $s_{ii} = t_i + e$ regardless of the taxation principle.

Selecting a purchase method. Consumers purchase goods either in brick-and-mortar stores or online, whichever has a lower purchase cost. Regardless of taxation principles, consumers residing in region i always buy good i in brick-and-mortar stores in region i, not online, and pay taxes in region i; thus, $s_{ii} = t_i$. This is because consumers in region i pay a tax of t_i regardless of the method of purchase, and the cost of buying online, $p_i + t_i + e$, is higher than the cost of buying in a brick-and-mortar store, $p_i + t_i$. In contrast, when consumers residing in region i buy good

[10] When goods are purchased online, it takes a certain amount of time for the goods to reach the consumer via delivery. With this view, Miyatake et al. (2016) estimated the cost of purchasing goods online, or e in our model, to be \$7.5 per item.

$j(\neq i)$, there are two ways to purchase it: First, they go to region j to buy it at a brick-and-mortar store. The second option is to buy good j online. In the former, the cost incurred is $p_i + t_i + \delta x_{ij}$. The second term is the origin-based tax, and the third term is the expense to travel to region j. In the latter case, that is, online purchases, the cost incurred depends on the tax principle applicable to goods bought online. If the origin principle is applied, the cost incurred by consumers is $p_j + t_j + e$. If the destination principle is applied, the cost incurred is $p_j + t_i + e$. The applied tax rate depends on the tax principles.

The travel distance from the place of residence in region i to region j, x_{ij}, is different for consumers, and the two purchase methods are indifferent in terms of the distance at $\hat{x}^O_{ij}$ satisfying

$$p_j + t_j + \delta \hat{x}^O_{ij} = p_j + t_j + e \quad \rightarrow \quad \hat{x}^O_{ij} = \frac{e}{\delta} \tag{1}$$

if the origin principle of taxation applies to e-commerce, where O in the superscript represents the value when taxed, according to the origin principle. A consumer with x_{ij} satisfying $x_{ij} > \hat{x}^O_{ij}$ purchases good j online. Conversely, a consumer with x_{ij} satisfying $x_{ij} < \hat{x}^O_{ij}$ travels to region j and purchases good j at the brick-and-mortar store. Hence, we obtain

$$s^O_{ij}(x_{ij}) = \begin{cases} t_j + \delta x_{ij} & \text{if } 0 \leq x_{ij} \leq \hat{x}^O_{ij} \\ t_j + e & \text{if } \hat{x}^O_{ij} < x_{ij} \end{cases}, \tag{2}$$

indicating that costs other than prices vary according to distance from the border.

Next, if the destination principle of taxation is applied, $\hat{x}^D_{ij}$, where the choice between the two purchase methods is indifferent, satisfies

$$p_j + t_j + \delta \hat{x}^D_{ij} = p_j + t_i + e \quad \rightarrow \quad \hat{x}^D_{ij} = \frac{e}{\delta} + \frac{t_i - t_j}{\delta}, \tag{3}$$

where D represents the value when destination principle tax is applied. As in the previous case, a consumer with x_{ij} satisfying $x_{ij} > \hat{x}^D_{ij}$ purchases good j online, while a consumer with x_{ij} satisfying $x_{ij} < \hat{x}^D_{ij}$ purchases it in a brick-and-mortar store. In this case, costs other than the price are

$$s^D_{ij}(x_{ij}) = \begin{cases} t_j + \delta x_{ij} & \text{if } 0 \leq x_{ij} \leq \hat{x}^D_{ij} \\ t_i + e & \text{if } \hat{x}^D_{ij} < x_{ij} \end{cases}. \tag{4}$$

What makes (4) different from (2) is that different taxes are applied when buying goods online. Assuming $t_i > t_j$, Fig. 1 shows s_{ij} for each taxation principle. In both Fig. 1a and b, consumers residing in region i who compare the costs of online and in-store purchases are more likely to purchase good j in stores if the distance from their residence to the border, x_{ij}, is shorter, and conversely, they are more likely to purchase online if the distance is farther. The two figures look similar, but a key difference arises under the two taxation principles: The critical point that divides

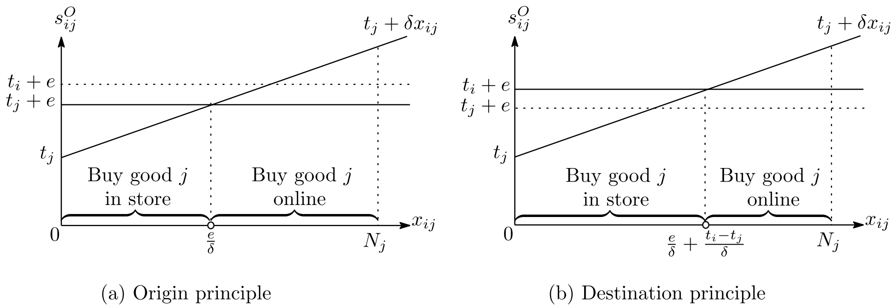


Fig. 1 Choice of how to buy good j by consumers in region i when $t_i > t_j$. Note. x_{ij} is the distance from the consumer's location in region i to the store in region j. The farther consumers are from the border, the more they purchase goods online. In (**a**), the point that determines the number of online users is not affected by the tax, but in (**b**), it is affected by the tax rates in both regions

online and offline purchases is affected by tax rates when taxed under the destination principle (Fig. 1b and Eq. 3), but not when taxed under the origin principle (Fig. 1a and Eq. 1). Under an origin-based tax, consumers pay taxes to the region where goods are supplied regardless of the purchase method; therefore, the distance for determining the purchase method is not affected by the tax rate. In contrast, under a destination-based tax, the tax rate will affect consumers' choice of purchase method because the tax rate will be different for the same good when purchased online versus when purchased in a brick-and-mortar store.

Based on the classification according to the two taxation principles shown in Fig. 1a and b, it is intuitive that under the destination principle of taxation, regional governments have incentives to manipulate tax rates to encourage consumers in their home regions to buy goods online from other regions because $\hat{x}_{ij}^D$ depends on the tax rates. There is no such incentive when taxing under the origin principle of taxation because changing the tax rate will not influence consumers' choice of how to buy.

2.2 Consumers

The demand function is assumed to be elastic to the cost of purchase, consisting of the price of the good, the tax rate, and the cost of traveling or online purchase, as follows:[11]

$$q_{ii} = \alpha - [p_i + s_{ii}], \tag{5}$$

$$q_{ij}(x_{ij}) = \alpha - [p_j + s_{ij}(x_{ij})], \tag{6}$$

[11] See Aiura and Ogawa (2021) for the process of deriving these demand functions. The assumption of a linear demand function is particularly essential for solving the tax competition model analytically, but it does not significantly alter the results, at least if the analysis is limited to the neighborhood of the equilibrium (Devereux et al., 2008)

where q_{ii} and q_{ij} denote the individual consumption of consumers living in region i for goods i and j, respectively. The former is the same for consumers in the same region regardless of their location, whereas the latter depends on the distance x_{ij} from the consumer's location to the border.

2.2.1 Individual consumption under the origin principle tax

Individual consumption under the origin principle tax can be obtained explicitly by substituting $s_{ii} = t_i$ and (2) into (5) and (6). While all consumers in region i purchase good i in the brick-and-mortar store, some purchase good j in stores in region j and the remainder purchase it online. Let Case A (in-store purchase) be the pattern in which consumers buy goods in brick-and-mortar stores and Case B (online purchase) be the pattern in which they buy goods online. The individual consumption of a consumer with x_{ij} in region i purchasing goods i and j is shown for each case, as follows:

Case A (In-store purchase):

For all consumers in region i who buy good i:

$$q_{ii}^{O} = q_{ii}^{OA} \equiv \alpha - (p_i + t_i). \tag{7}$$

For consumers with x_{ij} satisfying $0 \leq x_{ij} \leq \hat{x}_{ij}^{O}$ who buy good j;

$$q_{ij}^{O}(x_{ij}) = q_{ij}^{OA}(x_{ij}) \equiv \alpha - (p_j + t_j + \delta x_{ij}). \tag{8}$$

Case B (Online purchase): For consumers with x_{ij} satisfying $\hat{x}_{ij}^{O} \leq x_{ij}$ who buy good j;

$$q_{ij}^{O}(x_{ij}) = q_{ij}^{OB} \equiv \alpha - (p_j + t_j + e). \tag{9}$$

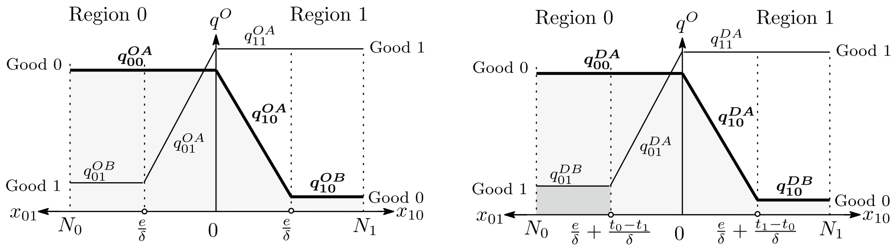
(7) represents the demand for good i by consumers in region i. (8) and (9) represent the demand for good j by consumers in region i which is relatively short and far from the border, respectively. Because of the complexity of the notation owing to multiple goods, regions, purchase methods, and taxation methods, we list the main variables in Table 1.

Figure 2a illustrates (7)–(9). Consider consumers in region 0 living between N_0 and e/δ. They purchase q_{00}^{OA} for good 0 at a brick-and-mortar store and q_{01}^{OB} for good 1 online. Because consumers in region i living far from the border purchase good j online, their costs are independent of their distance to the border. Hence, q_{01}^{OB} and q_{00}^{OA} are constant, regardless of where the consumer resides. Consumers in region 0 whose distance to the border is shorter than e/δ purchase q_{00}^{OA} of good 0 and $q_{01}^{OA}(x_{ij})$ of good 1 at brick-and-mortar stores. The shorter the distance to the border, the lower the travel cost required to buy good 1; thus, consumers purchase more of good 1. Since the two goods are independent, q_{00}^{OA} is unchanged even if q_{01}^{OA} varies with distance from the border. The same applies to region 1. The demand for the two goods by consumers in region 1 living between e/δ and N_1 is q_{10}^{OB} and q_{11}^{OA}, respectively, regardless of the distance to the border. Consumers in region 1 whose

Table 1 Notation of variables

δ	Travel cost per distance
e	Cost of purchasing goods online
x_{ij}	Travel distance from region i to region j
p_i	Price of good i
t_i	Tax rate of region i
s_{ij}^k	Cost that a consumer in region i incurs when purchasing goods produced in region j under the k's principle of taxation on good j
$\hat{x}_{ij}^k$	Distance to the border of consumer in region i where online and in-store purchases are indifferent under the k's principle of taxation on good j
q_{ii}^{kA}	Demand for good i by consumers in region i who purchase good i at the brick-and-mortar store in region i (Case A) under the k's principle of taxation
q_{ij}^{kA}	Demand for good j by consumers in region i who purchase good j at the brick-and-mortar store in region j (Case A) under the k's principle of taxation
q_{ij}^{kB}	Demand for good j by consumers in region i who purchase good j online (Case B) under the k's principle of taxation

$k = D$ means destination principle, and $k = O$ means origin principle. A and B correspond to the cases where goods are purchased in stores and online, respectively. Since consumers in region i can purchase good i with zero travel costs, the option to purchase those goods online does not appear in the model



(a) Origin principle (b) Destination principle

Fig. 2 Individual consumption when $t_0 > t_1$. *Note*. The distance x_{01} (x_{10}) is measured from the origin to the border from the residence in region 0 (1) in the left (right) direction. The thick line (solid line) represents the individual consumption for good 0(1) by consumers living at a different distance from the border. The tax rate of region 0 is applied to consumption in the areas shown in gray, i.e., the area in gray is the tax base of region 0

distance to the border is shorter than e/δ purchase $q_{10}^{OA}(x_{ij})$ for good 0 and q_{11}^{OA} for good 1 at the stores. Again, consumers who travel shorter distances purchase more good 0.

2.2.2 Individual consumption under the destination principle tax

Similarly, individual consumption under the destination principle tax can be obtained by substituting $s_{ii} = t_i$ and (4) into (5) and (6). Case A is the individual consumption of a consumer in region i who purchases goods in a brick-and-mortar store, and Case B is the individual consumption of a consumer in region i who purchases good j online.

Case A (In-store purchase):

For all consumers in region i who buy good i:

$$q_{ii}^{DA} = q_{ii}^{DA} = q_{ii}^{OA}. \tag{10}$$

For consumers with x_{ij} satisfying $0 \le x_{ij} \le \hat{x}_{ij}^{D}$ who buy good j;

$$q_{ij}^{D}(x_{ij}) = q_{ij}^{DA}(x_{ij}) = q_{ij}^{OA}(x_{ij}). \tag{11}$$

Case B (Online purchase): For consumers with x_{ij} satisfying $\hat{x}_{ij}^{D} < x_{ij}$ who buy good j;

$$q_{ij}^{D}(x_{ij}) = q_{ij}^{DB} \equiv \alpha - (p_j + t_i + e). \tag{12}$$

Again, consumers in region i living near the border purchase good j in brick-and-mortar stores, whereas consumers away from the border purchase good j online. Individual consumption under destination-based tax is shown in Fig. 2b.

The differences in individual consumption indicated by (9) and (12) lie in the tax rate applied; in the former, consumers in region i pay t_i when they purchase good j online, whereas, in the latter, they pay t_j. This leads to a significant difference between Fig. 2a and b. In Fig. 2a, the point at which the purchase method is indifferent is uniquely determined at e/δ independent of the tax rate, whereas, in Fig. 2b, it depends on the difference in tax rates between the two regions.

2.3 Governments

Following a series of studies since Kanbur and Keen (1993), we assume that each government aims to maximize its tax revenue, given that the origin-based tax applies to purchases made in brick-and-mortar stores. When an origin-based tax is applied to goods purchased online, the tax revenue in region i is

$$\begin{aligned} &R_i^O = t_i^O Q_i^O, \text{ where} \\ &Q_i^O \equiv N_i q_{ii}^{OA} + \int_0^{\min[\hat{x}_{ji}^O, N_j]} q_{ji}^{OA}(x_{ji})\mathrm{d}x_{ji} + (N_j - \min[\hat{x}_{ji}^O, N_j])q_{ji}^{OB}. \end{aligned} \tag{13}$$

The first term in (13) is the aggregate consumption of good i by consumers in region i. The second and third terms in (13) represent the aggregate consumption of good i by consumers in region j, with the former representing in-store purchases and the latter online purchases. In Fig. 2a, the gray area corresponds to the tax base of region 0 under the origin principle of taxation, Q_i^O.

If the origin-based tax is applied to purchases of goods in brick-and-mortar stores, but the destination-based tax is applied to e-commerce, the tax revenue in region i is expressed as follows:

$$R_i^D = t_i^D Q_i^D, \text{ where}$$
$$Q_i^D = N_i q_{ii}^{DA} + \int_0^{\min[\hat{x}_{ji}^D, N_j]} q_{ji}^{DA}(x_{ji})\mathrm{d}x_{ji} + (N_i - \min[\hat{x}_{ij}^D, N_i])q_{ij}^{DB}. \tag{14}$$

The first term in (14) is the aggregate consumption of good i by consumers in region i. The second term is the aggregate consumption of consumers in region j who purchase good i in brick-and-mortar stores in region i, and the third term is the aggregate consumption of good i online. In Fig. 2b, the gray area corresponds to the tax base of region 0 under the destination principle, Q_i^D, where the area in darker gray is counted twice in the calculation of the tax base.

The key difference between Q_i^O and Q_i^D is that the subscript of q is ji in the last term of (13), q_{ji}^{OB}; however, it is replaced by ij in (14), q_{ij}^{DB}. This is because the tax in region i is applied under the origin (destination) principle tax on the consumption of good i (j) purchased online by consumers in region j (i).

2.4 Equilibrium without online purchases

First, we show the equilibrium of the symmetric model, that is, $N_0 = N_1 = 1$, with no online purchase. Another extreme case where all consumers purchase goods exclusively online is considered in Sect. 5.2. For this, we assume a situation in which the online purchase cost e is sufficiently high such that consumers do not have the option to purchase goods online. By comparing the equilibrium obtained here with that of the model that allows online purchases presented in Sect. 3, we observe the impact of the emergence of e-commerce.

When online purchase cost e is sufficiently high, $\hat{x}_{ij}^O$ and $\hat{x}_{ij}^D$ are larger than $N_i(=1)$, and (13) and (14) can be expressed as follows:

$$R_i^N = t_i^N Q_i^N, \text{ where } Q_i^N \equiv N_0 q_{ii}^{NB} + \int_0^{N_1} q_{ji}^{NA}(x_{ji})\mathrm{d}x_{ji} = q_{ii}^{OA} + \int_0^1 q_{ji}^{OA}(x_{ji})\mathrm{d}x_{ji}. \tag{15}$$

The superscript N indicates that it is a variable in the model with no e-commerce. As all consumers purchase both goods at the brick-and-mortar store, $q_{ii}^{NB} = q_{ii}^{OB}$ and $q_{ji}^{NB} = q_{ji}^{OB}$ hold. The first-order condition for maximizing R_i^N with respect to t_i^N is as follows:

$$\frac{\partial R_i^N}{\partial t_i^N} = Q_i^N + t_i^N \frac{\partial Q_i^N}{\partial t_i} = 0, \tag{16}$$

which includes the two conflicting effects of increasing tax rates on tax revenue. The first term in (16) represents an increase in tax revenue per tax base, and the second term represents a decrease in tax revenue due to a contraction of the tax base caused by a decrease in demand. If goods are inelastic, the second term would disappear, and the tax rate would be infinite. Substituting $p_i = p_j = c$, $N_i = N_j = 1$, (7) and (8) into Q_i^N in (15), we obtain:

$$Q_i^N = 2\left[A - \left(t_i^N + \frac{\delta}{4}\right)\right],$$

where $A \equiv \alpha - c$. Using this equation with $\partial Q_i^N/\partial t_i = -2$, (16) can be rewritten as follows:

$$\frac{\partial R_i^N}{\partial t_i^N} = 2\left(A - t_i^N - \frac{\delta}{4}\right) - 2t_i^N = 0. \tag{17}$$

Since goods i and j are independent in our model, tax rate in one region is also independent of the tax rate in other region. Using (17), we can solve for the tax rate and tax revenues of the equilibrium when consumers do not have a channel for online purchases, as follows:

$$t_i^{N*} = \frac{A}{2} - \frac{\delta}{8}, \tag{18}$$

$$R_i^{N*} = 2(t_i^{N*})^2 = 2\left(\frac{A}{2} - \frac{\delta}{8}\right)^2. \tag{19}$$

3 Equilibrium under the origin principle of taxation

We present a symmetric model for online purchases. In this section, origin-based tax applies when goods are purchased in a brick-and-mortar store or through e-commerce, deferring a discussion of equilibrium under destination-based tax on e-commerce until later. If the cost of purchasing goods online is too high and consumers who purchase goods online disappear from the economy, then the equilibrium would be that presented in Sect. 2.4. Therefore, we make the following assumption to validate online purchases:

Assumption 1 $e < \delta$.

The tax base for region i is obtained by using $p_i = p_j = c$, $N_i = N_j = 1$, (1), (7), (8), (9), and (13) as

$$Q_i^O = 2\left[A - \left(t_i^O + \frac{2\delta - e}{4\delta}e\right)\right]. \tag{20}$$

The impact on the tax base of a tax change is simple: $\partial Q_i^O/\partial t_i = -2$. Using (20), the first-order condition for maximizing $R_i^O = t_i^O Q_i^O$ is

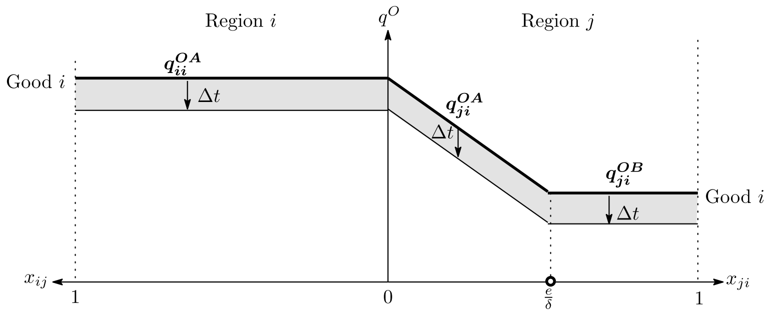


Fig. 3 Change in individual consumption taxed by region i when t_i increases by Δt: origin principle of taxation. Note. The bold and thin lines represent individual consumption before and after the tax rate in region i is raised by Δt, respectively. The change in the tax base resulting from the tax increase is shown in the gray area, which applies to subsequent figures

$$\begin{aligned}\frac{\partial R_i^O}{\partial t_i^O} &= Q_i^O + t_i^O \frac{\partial Q_i^O}{\partial t_i^O} \\ &= 2\left(A - t_i^O - \frac{2\delta - e}{4\delta} e\right) - 2t_i^O = 0.\end{aligned} \tag{21}$$

The first term on the right-hand side of (21) represents the effect of increased revenue associated with a tax increase when the tax base remains unchanged. The second term represents the impact of a reduced tax base resulting from a tax increase, a consequence that dissipates if the good is inelastic in terms of tax-price. The latter effect is depicted in Fig. 3, which illustrates how individual consumption subject to taxation in region i varies with distance to the border. Under the origin-based tax regime, the tax base of region i corresponds to the quantity of good i purchased by consumers, indicated by the bold line in the figure. Subsequently, as is evident from (7) to (9), increasing t_i by Δt results in a uniform reduction of Δt in the purchase of good i for all consumers, leading to a corresponding contraction in the tax base. This is captured by the second term in (21) and represented by the gray area in Fig. 3.

It is particularly noteworthy in (21) that, in the context of origin principle taxation, the tax rate for region i remains unaffected by the tax rate applied to region j. This arises from the observation in Fig. 1a that an origin-based tax is levied on both in-store and online purchases, making the tax independent of the consumer's choice when purchasing goods. Consequently, there is no strategic incentive for the government to manipulate tax rates to deprive other regions of their tax bases.

Using (21), we solve for the tax rate and tax revenue under the origin principle of taxation:

$$t_i^{O*} = \frac{A}{2} - \frac{2\delta - e}{8\delta} e, \tag{22}$$

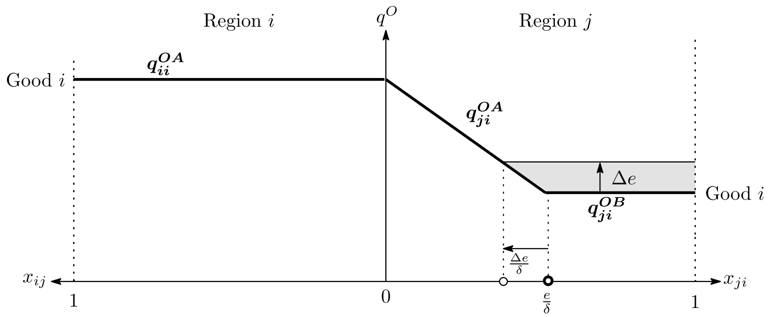


Fig. 4 Change in individual consumption taxed by region i when e declines: origin principle of taxation

$$R_i^{O*} = 2(t_i^{O*})^2 = 2\left(\frac{A}{2} - \frac{2\delta - e}{8\delta}e\right)^2. \tag{23}$$

We now express the progress of e-commerce as a decline in eAgrawal and Wildasin (2020). By differentiating t_i^{O*} with respect to e in (22), we can formally show the impact of the development of online purchasing on the equilibrium tax rate under the origin principle of taxation as follows:

Proposition 1 *Under the origin principle of taxation, as the cost of online consumption decreases, taxes increase,* $\partial t_i^{O*}/\partial e < 0$.

Proof Using (22), we obtain

$$\frac{\partial t_i^{O*}}{\partial e} = -\frac{\delta - e}{4\delta} < 0.$$

The sign is based on Assumption 1. □

Furthermore, we can easily show that $\partial R_i^{O*}/\partial e = 2t_i^{O*}(\partial t_i^{O*}/\partial e) < 0$, which means that the increase in t_i^{O*} associated with a decrease in e leads to an increase in R_i^{O*}.

The tax increases as online purchase cost decrease because the decrease in e increases the marginal revenue from a higher tax rate:

$$\begin{aligned} \frac{\partial^2 R_i^O}{\partial t_i^O \partial e} &= \frac{\partial Q_i^O}{\partial e} + t_i^O \overbrace{\frac{\partial^2 Q_i^O}{\partial t_i \partial e}}^{=0} \\ &= -\left(1 - \frac{e}{\delta}\right) < 0. \end{aligned} \tag{24}$$

In (24), there are two possible effects of a decline in e on the marginal revenue. The first is the effect of the decrease in e directly changing the tax base through changes in how, and how many purchases are made. This is captured by the first term on the right-hand side of (24). The second is the indirect effect of a decrease in e that changes the sensitivity of the tax base to tax rates, as indicated by the second term. However, because $\partial Q_i^O/\partial t_i = -2$ in (20), no indirect effects occur in our model. Thus, the second term is zero.

The direct effect of the decline in e on the tax base, that is, the first term, can be broken down into two parts: (i) A decrease in the cost of online purchases increases the number of consumers who purchase goods online, and (ii) lower online purchase costs increase the quantity of goods purchased online. While (i) there is an element included in the model of Agrawal and Wildasin (2020), and (ii) there is a novel effect incorporated in our model that accommodates price-elastic goods and is absent from their analysis. This addition increases the origin-based tax rate by reducing online costs, as explained in the subsequent discussion. Figure 4 illustrates these two effects, where the bold line shows the individual consumption of good i in region i and region j. The change in the number of online users with a marginal decrease in e is indicated by the horizontal arrow; the decrease in e increases the number of online users by $\Delta e/\delta$ and reduces the number of offline users by the same amount. When consumers switch from online to offline purchases, consumption before and after the switch is the same for marginal consumers whose purchase methods are indifferent, and the expansion of the tax base through an increase in online users is offset by a contraction in the tax base through a decrease in offline users at the margin. In fact, the increase in the tax base through path (i) is $(\Delta e)^2/(2\delta)$ in Fig. 4, which converges to zero when $\Delta e \to 0$. Therefore, path (i) does not affect the tax base, and the tax rate does not change along this path. The sign in (24) is owing to path (ii), indicated by a vertical arrow. A decrease in online costs increases consumers' purchases of good i in region j by Δe. Thus, as e decreases, the tax base in region i shows a net increase. The larger the tax base, the greater the marginal revenue when taxes are raised; thus, a larger tax base due to a lower e increases the incentive to set higher tax rates.

In our analysis, as detailed above, we have made the following assumption that ensures a normal situation in which the consumption of goods in equilibrium is positive, $q_{ii}(x_{ij}) > 0$ and $q_{ij}(x_{ij}) > 0$, for any x_{ij} and e under Assumption 1 (see Appendix A).

Assumption 2

$$\alpha > \bar{\alpha} \equiv c + \frac{7}{4}\delta \quad \leftrightarrow \quad A > \frac{7}{4}\delta.$$

Finally, we formally derive the impact of the emergence of a new means of purchasing online on tax rates and revenue. By comparing (18) and (19) with (22) and (23), we obtain the following results:

Corollary 1 *If an origin-based tax is applied, tax rates and tax revenues are higher when goods can be purchased online than when they cannot*: $t_i^{N*} < t_i^{O*}$ and $R_i^{N*} < R_i^{O*}$.

Proof The comparison gives

$$t_i^{O*} - t_i^{N*} = \frac{(\delta - e)^2}{8\delta} > 0,$$
$$R_i^{O*} - R_i^{N*} = 2(t_i^{O*})^2 - 2(t_i^{N*})^2 = 2(t_i^{O*} + t_i^{N*})(t_i^{O*} - t_i^{N*}) > 0.$$

□

The demand for goods produced in other regions will increase when consumers can purchase goods online because the cost is lower than when they can only purchase goods in brick-and-mortar stores. This implies an increase in the tax base in the presence of e-commerce, which allows governments to impose higher taxes and generate higher tax revenues.

4 Equilibrium under the destination principle of taxation

This section derives an equilibrium in which destination-based tax applies to the online purchase of goods, whereas origin-based tax applies to the purchase of goods in brick-and-mortar stores.

By inserting $p_i = p_j = c$, $N_i = N_j = 1$, and (3), (10), (11), and (12) into (14), we obtain the tax base for region i:

$$Q_i^D = \left(1 - \frac{E_j}{\delta}\right)[2A - (2t_i^D + e)] + \frac{2e}{\delta}(A - t_i^D) - \frac{E_i^2}{2\delta}, \tag{25}$$

where $E_i = e - (t_i^D - t_j^D)$. The change in the tax base relative to the change in the tax rate is given by

$$\frac{\partial Q_i^D}{\partial t_i} = -2 - \frac{2}{\delta} \underbrace{(A - t_i - e)}_{q_{ij}^{DB}} + \frac{t_i - t_j}{\delta}. \tag{26}$$

When an origin-based tax is applied, $\partial Q_i^O / \partial t_i = -2$, corresponding to the first term on the right-hand side of (26). Thus, for symmetric regions ($t_i = t_j$), the increase in the tax base under a marginal reduction in the destination-based tax rate is greater than that under an origin-based tax because of the presence of the second term on the right-hand side of (26).

Maximizing $R_i^D = t_i^D Q_i^D$ yields the following first-order condition:

$$\begin{aligned}\frac{\partial R_i^D}{\partial t_i^D} &= Q_i^D + t_i^D \frac{\partial Q_i^D}{\partial t_i^D} \\ &= 2\left(A - t_i^D - \frac{2\delta - e}{4\delta}e\right) - 2t_i^D - \left[\frac{2}{\delta}(A - t_i^D - e)t_i^D \right. \\ &\qquad \left. -(2A - 3t_i^D - 2e)\frac{t_j^D - t_i^D}{\delta} + \frac{(t_j^D - t_i^D)^2}{2\delta}\right] = 0,\end{aligned}$$

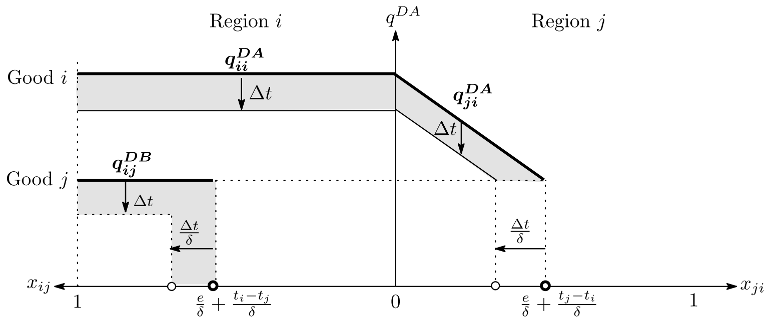


Fig. 5 Change in individual consumption taxed by region i when t_i increases by Δt: destination principle of taxation

yielding the reaction function $t_i^D = t(t_j^D)$. The third term in this equation includes t_j^D and results in a reaction function with properties quite different from those under the origin principle tax, which is given by (21). As shown in Fig. 1b, when an origin-based tax is imposed on in-store purchases and a destination-based tax is applied to online purchases, the tax has the potential to affect consumers' decisions regarding their preferred method of purchasing goods. Consequently, the government is motivated to manipulate tax rates to expand the local tax base, thereby engendering the classic race for lower tax rates.

To evaluate the first-order condition at the symmetric equilibrium, we set $t_i^D = t_j^D$, which gives

$$\left.\frac{\partial R_i^D}{\partial t_i^D}\right|_{t_i^D=t_j^D} = \underbrace{2\left(A - t_i^D - \frac{2\delta - e}{4\delta}e\right)}_{Q_i^D} - 2t_i^D - \frac{2}{\delta}\underbrace{\left(A - t_i^D - e\right)}_{q_{ij}^{DB}} t_i^D = 0. \tag{27}$$

The first-order condition has two solutions, and only the smaller solution satisfies the second-order condition (see Appendix B). Figure 5 shows individual consumption subject to a tax for region i under the destination principle tax. The first term on the right-hand side of (27), which corresponds to tax base Q_i^D, is represented by the integral along the bold line in the figure. The second and third terms in (27) represent $t_i^D(\partial Q_i^D/\partial t_i^D)$, which show the impact of the tax base reduction due to the tax increase in tax revenues. $\partial Q_i^D/\partial t_i^D$ is captured visually by the total change in consumption, as indicated by the five arrows in Fig. 5. This has the following two properties that differ from those in Fig. 3 under the origin-based taxation: First, regarding the downward arrows that capture the decline in individual consumption due to the tax increase, the downward arrow for q_{ji}^{OB} in Fig. 3 is replaced by the downward arrow for q_{ij}^{DB} in Fig. 5. This is because under the origin principle tax, online purchases by consumers in region j (q_{ji}^{OB}) form part of the tax base of region i, whereas under the destination principle tax, online purchases by consumers in region i (q_{ij}^{DB}) now form the tax base. However, there is no change in the amount of decline in individual consumption associated with the tax increase when the tax base is replaced from q_{ji}^{OB} to q_{ij}^{DB}, and therefore, there is no difference between the two tax principles in effect through the change in consumption on the determination of the tax rate. This is confirmed by the fact that the first two terms are the same as those in (21) and (27). Second, as captured by the two left arrows, the increase in t_i reduces the number of consumers paying taxes to region i in Fig. 5, but there is no such change in Fig. 3. This change is what causes the difference between origin-based and destination-based tax rates.

Specifically, under the destination principle, changing the tax rate in region i changes the number of consumers paying taxes to region i. For example, increasing t_i by Δt causes $\Delta t/\delta$ consumers in region j to switch from in-store to online purchases of good i and $\Delta t/\delta$ consumers in region i to switch from online to in-store purchases of good j. Such a change in purchasing methods reduces the number of consumers paying taxes in region i by $2\Delta t/\delta$. As the consumption of consumers who switch purchase methods is equal to q_{ij}^{DB} in Fig. 5, tax revenue is reduced by the reduction in the number of consumers paying taxes in region i when t_i is raised, which is equal to $2\Delta t/\delta$ multiplied by q_{ij}^{DB}. This is captured by the third term in (27). These effects, which were not present when the origin principle tax was applied, are added in the case of the destination principle tax so that the two tax principles lead to different equilibrium tax rates.

Next, we evaluate (27) at t_i^{O*} to determine how the equilibrium tax rates differ under the two tax principles. From (22) and (27), we obtain

$$\left.\frac{\partial R_i^D}{\partial t_i^D}\right|_{t_i^D=t_j^D=t_i^{O*}} = -\frac{t_i^{O*}}{\delta}\underbrace{\left(A-\frac{3}{2}e-\frac{e^2}{4\delta}\right)}_{q_{ij}^{OB}|_{t_i^O=t_j^O=t_i^{O*}}>0} < 0, \tag{28}$$

because the brackets in (28) are identical to q_{ij}^{OB} in the symmetric equilibrium under the origin-based taxation. Therefore, we obtain the following proposition.

Proposition 2 *The tax rate is lower under the destination principle than it is under the origin principle.* $t_i^{D*} < t_i^{O*}$.

The intuitive mechanism for this result is as follows. In the case of taxing online purchases of goods under the destination principle, the government in region i can induce consumers in region j who purchase goods online from region i to purchase goods in stores. Simultaneously, a reduction in the tax rate in region i can induce consumers in region i who used to buy goods from brick-and-mortar stores in region j to buy them online. This leads to an increase in the tax base and provides an incentive for region i to lower its tax rate. This effect does not occur under the origin principle of taxation. Therefore, the equilibrium tax rate under the destination principle is lower than that under the origin principle.

Proposition 2 immediately yields the following result for the comparison of tax revenue in equilibrium under different tax principles:

Proposition 3 *Tax revenue is lower under the destination principle than it is under the origin principle.* $R_i^D|_{t_i=t_j=t_i^{D*}} < R_i^O|_{t_i=t_j=t_i^{O*}}$.

Proof At symmetric equilibrium,

$$R_i^D|_{t_i^D=t_j^D=\hat{t}} = R_i^O|_{t_i^O=t_j^O=\hat{t}} = 2\Big(A - \frac{2\delta - e}{4\delta}e - \hat{t}\Big)\hat{t},$$

which is inverted U-shaped with respect to $\hat{t}$ and is maximized at

$$\hat{t}^* = \frac{A}{2} - \frac{2\delta - e}{8\delta}e = t_i^{O*}.$$

Since $t_i^{D*} < t_i^{O*}$, we obtain $R_i^D|_{t_i=t_j=t_i^{D*}} < R_i^O|_{t_i=t_j=t_i^{O*}}$. □

Next, we consider how the tax rate changes when the cost of online purchases decline. The equilibrium tax rate under the destination principle is determined at the level at which (27) is set to zero:

$$t_i^{D*} = \frac{2\delta - e}{2} + \frac{A - \sqrt{A^2 - 2(A+\delta)e + 4\delta^2}}{2}. \tag{29}$$

We differentiate (27) by e to determine how t_i^D changes as e decreases:

$$\left.\frac{\partial^2 R_i^D}{\partial t_i^D \partial e}\right|_{t_i^D=t_j^D} = \underbrace{-\Big(1 - \frac{e}{\delta}\Big)}_{\partial Q_i^D/(\partial e)} + \underbrace{\frac{2}{\delta}}_{\partial^2 Q_i^D/(\partial t_i^D \partial e)} \times t_i^D. \tag{30}$$

The first term in (30) is the same as that derived from (24) and captures the direct impact of a lower e on the tax base. It is immediately clear from (10)–(12) that the change in individual consumption in response to a change in e is independent of the tax rate. Furthermore, as Fig. 1b shows, changes in the number of online users in response to changes in e are independent of the tax rate. Because the tax base is determined by individual consumption and the number of consumers, the change in the tax base due to a change in e is equal at any tax rate and tax principle. The second term in (30) captures the change in sensitivity of the tax base to tax as e decreases. This term is not zero but positive under destination principle taxation, suggesting that a decrease in e reduces the sensitivity of the tax base to tax rates. This is because the third term in (27), part of $\partial Q_i^D/\partial t_i^D$, includes individual consumption, which increases with a lower e and strengthens tax competition. Because of this term, unlike the origin principle tax, a decrease in e may result in a decrease in the tax rate for the destination principle tax.

If the negative effect of the first term in (30) exceeds that of the second, a decrease in e increases t_i^D. Conversely, if the negative effect is smaller than the positive effect, then a decrease in e decreases t_i^D. The former leads to the same result as Proposition 1: when taxing e-commerce under the principle of origin, a decrease in e causes an increase in the tax rate. Interestingly, in contrast with applying the origin principle tax to e-commerce, a decline in e may cause a decline in tax rates when applying the destination principle, exacerbating the race for lower taxes. To determine how likely it is that a decrease in e lowers the tax rate, we examine the change in marginal revenue associated with a tax increase due to a decrease in e. Note that the right-hand side of (30) is an increasing function of e/δ. By substituting $e/\delta = 0$, we obtain

$$\left.\frac{\partial^2 R_i^D}{\partial t_i^D \partial e}\right|_{t_i^D = t_j^D} > \frac{2}{\delta}\left(t_i^D - \frac{\delta}{2}\right). \tag{31}$$

From (31), if $t_i^D > \delta/2$, which holds in the following proposition under Assumptions 1 and 2, the positive effect of the second term in (30) outweighs the negative effect of the first term, and a decline in the cost of online purchases accelerates the race to lower tax rates under the destination principle of taxation. The formal result is presented in the following proposition.

Proposition 4 *Under the destination principle of taxation, as the cost of online consumption decreases, tax rates decrease,* $\partial t_i^{D*}/\partial e > 0$.

Proof See Appendix C. □

Proposition 4 contrasts with Proposition 1. Under the origin principle of taxation, increased demand due to lower online purchase costs will increase the tax base, thus increasing the incentive for regional governments to set higher tax rates. However, under the destination principle tax, the result is the opposite. Basically, when goods purchased online are taxed under the destination principle, the government in region i has an incentive to lower the tax rate to induce consumers in region j to buy good i in brick-and-mortar stores and to make consumers in region i buy good j online. In this case, as the cost of online purchase declines and the attractiveness of online consumption increases, governments must lower tax rates to a greater extent to counteract the effect of the lower costs of online shopping and induce customers to visit brick-and-mortar stores. For this reason, the sign of $\partial t_i^{D*}/\partial e$ is positive; the smaller the value of e, the more likely consumers are to buy goods online, so in order to induce consumers in region j to buy in brick-and-mortar stores in region i, the tax rate in region i needs to be reduced. Hence, in contrast with the results obtained under origin-based taxation, a decline in the cost of online purchases lowers tax rates and worsens tax competition under destination-based taxation.

We derive two policy implications from Propositions 1 to 4: First, given that an origin-based tax is applied to the purchase of goods in brick-and-mortar stores, taxing online purchases of goods under the origin principle is superior to taxing them under the destination principle from a revenue-maximizing viewpoint. Although origin-based taxes are neutral to the consumer's decision on how to purchase goods, destination-based taxes distort this decision, thus encouraging the latter to compete with lower tax. Second, as the cost of online purchases decreases and online consumption expands, the advantage of taxing goods purchased online under the origin principle is strengthened.

5 Extension

Among the several assumptions made in the analysis thus far, this section first discusses the properties of equilibrium when the regions are asymmetric. So far, we have assumed that the two regions are symmetric, which is necessary for obtaining analytical solutions. In Sect. 5.1, with the help of numerical analysis, we examine the properties of equilibrium in the case of two regions of different sizes, $b > 0$, and clarify how the tax rate will change as the online market expands owing to lower online costs. Because the process of finding the equilibrium is the same as that in the previous sections, we focus only on new findings that can be drawn owing to population differences between regions. Section 5.2 refers to the equilibrium at which all consumers purchase goods exclusively online. This may not be a realistic given the current situation, but it enables us to study an extreme case in which there is no longer a choice of how goods are purchased, and thus, it clarifies the critical role of the choice in "how to purchase" on the efficiency of the tax principle.

5.1 Asymmetric equilibrium

5.1.1 Origin principle of taxation

To validate online purchases in both regions, we modify Assumption 1 as follows:

Assumption 1′ . $e < \delta(1 - b)$.

The equilibrium tax rates under the origin principle of taxation are obtained as follows (see Appendix D):

$$t_0^{O*} = \frac{A}{2} - \frac{(1-b)e}{4} + \frac{e^2}{8\delta} \text{ and } t_1^{O*} = \frac{A}{2} - \frac{(1+b)e}{4} + \frac{e^2}{8\delta}. \tag{32}$$

Note that (32) reduces to (22) if $b = 0$. A comparison of the equilibrium tax rates and tax revenues derived using (32) for the two regions yields the following result:

Proposition 5 *When the population of region* 0 *is larger than that of region* 1 ($b > 0$), *the tax rate and tax revenue in region 0 are higher than those in region* 1, $t_0^{O*} > t_1^{O*}$ *and* $R_0^{O*} > R_1^{O*}$.

Proof The two equations in (32) yield $t_0^{O*} - t_1^{O*} = be/2 > 0$ because $b > 0$. Using $p_i = c$, (1), (7), (8), (9), (13), and (32), and taking the difference in equilibrium tax revenues, we obtain the following:

$$R_0^{O*} - R_1^{O*} = \frac{be}{4\delta}\left[2\delta(\delta - e) + \delta(4A - 7\delta) + 5\delta^2 + e^2\right] > 0.$$

Given $b > 0$, the sign holds because $\delta > e$ in Assumption 1′ and $4A - 7\delta > 0$ in Assumption 2. □

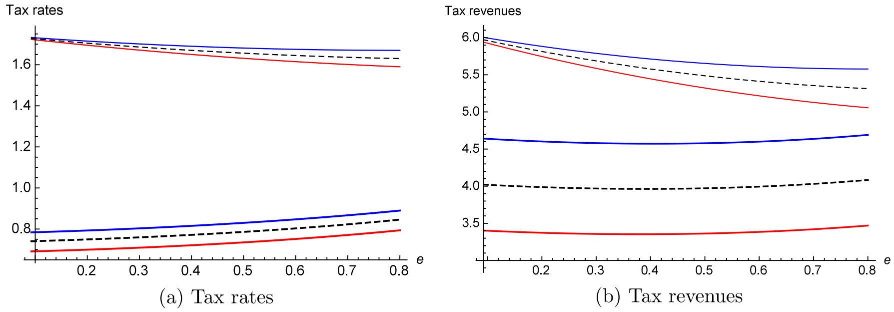


Fig. 6 Tax rates and tax revenues in two asymmetric regions ($b > 0$). Note. The blue line represents the tax rate and tax revenues for large region 0, and the red line represents that of small region 1. In (**a**), the lines where the tax rates are greater than 1.5 are the equilibrium tax rates under the origin principle, and the lines where the tax rates are less than 1.0 are the equilibrium tax rates under the destination principle. The same is true for (**b**): The lines at the high level are the tax revenues under the origin principle, and the lines at the low level are the tax revenues under the destination principle. The dotted line represents the tax rate and tax revenues for the case of two symmetric regions. The parameters are $\delta = 1, c = 1, \alpha = 4.5$, and $b = 0.2$

The result that regions with larger populations set higher tax rates has been a well-known view since Kanbur and Keen (1993), Trandel (1994), and Nielsen (2001). Proposition 5 confirms that this feature of the equilibrium tax rate holds robustly when the model is extended to a situation in which the consumption of goods is tax-price elastic and online purchases are possible.

Differentiating (32) with respect to e also provides following result:

Proposition 6 *The origin-based tax increases monotonically as the cost of online consumption* (e) *decreases in both regions*: $\partial t_0^O/\partial e < 0$ *and* $\partial t_1^O/\partial e < 0$.

Proof From (32), we obtain

$$\frac{\partial t_0^{O*}}{\partial e} = -\frac{1}{4}\left[\left(1 - \frac{e}{\delta}\right) - b\right] \quad \text{and} \quad \frac{\partial t_1^{O*}}{\partial e} = -\frac{1}{4}\left[\left(1 - \frac{e}{\delta}\right) + b\right]. \tag{33}$$

The first equation in (33) shows that $\partial t_0^{O*}/\partial e < 0$ under Assumption 1′. $\partial t_1^{O*}/\partial e < 0$ is straightforward from the second equation in (33). □

This result is the same as in Proposition 1, meaning that even when the size of the regions is asymmetric, the result that lower online purchase costs reduce tax rates still holds under origin principle taxation. We also find that when regions are asymmetric, tax rates differ across regions, but lower online costs reduce these differences, $\partial(t_0^{O*} - t_1^{O*})/\partial e = b/2 > 0$.

5.1.2 Destination principle of taxation

Even in our simple setting, it is difficult to analytically solve for equilibrium when asymmetric regions apply destination-based taxation to e-commerce. Therefore, we rely on numerical calculations to demonstrate the relationship between tax rates and the decline in online purchase costs for each region. Figure 6a shows the tax rates in the large and small regions under a set of plausible parameters within the range that satisfies the conditions corresponding to Assumptions 1′ and 2: $\delta = 1, c = 1, \alpha = 4.5$, and $b = 0.2$. The blue lines represent the large regions' tax rates, the red lines represent the small regions' tax rates, and the dotted line indicates the tax rates in the symmetric equilibrium. The lines at the high level (above 1.5) represent the tax rate under the origin principle, and the lines at the low level (below 1.0) represent tax rates under the destination principle.

5.1.3 Comparison of the two tax principles

From Fig. 6a, we can identify several features of the equilibrium tax rate under the two tax principles. First, under both tax principles, the tax rate in the larger region is higher than that in the smaller region, implying that the result in Proposition 5, derived under the origin principle of taxation, is also valid for taxation under the destination principle. Second, for all $e(< \delta(1 - b) = 0.8)$, the tax rate based on the destination principle is lower than that based on the origin principle, showing that what is shown in Proposition 2 holds even when there is a difference in the population of regions. Third, a decrease in e lowers tax rates in both regions under the destination principle but raises them under the origin principle.[12] These mean that the results shown in Propositions 1 and 4 are valid, even if we assume two asymmetric regions, which holds true even when the value of the parameter changed.

Figure 6b shows the tax revenue realized under the equilibrium tax rates in Fig. 6a. It shows the following two characteristics of tax revenue in regions with different population sizes. First, lower costs associated with online purchases tend to increase tax revenues under origin-based taxation but decrease tax revenues under destination-based taxation. Second, for any level of e, origin-based taxation generates greater tax revenue than destination-based taxation does. The second feature numerically confirms the advantage of the origin-based taxation presented in Proposition 3 in the framework of asymmetric regions. Specifically, assuming that origin-based taxation is applied to transactions in brick-and-mortar stores, these two remarks show that applying the same taxation principle to e-commerce, even

[12] In Agrawal and Wildasin (2020), under the destination-based tax on e-commerce, a decline in e lowers tax rates in large regions and raises rates in small ones. By contrast, our results under the destination principle show that a decline in e lowers the tax rates in both regions. This difference stems from the difference in the assumptions of the two studies: In the basic analysis of Agrawal and Wildasin (2020), goods purchased over the Internet are only sold in a core region, whereas in our model, goods can be purchased over the Internet in both regions. In their extended part of the analysis, they suggest that the results may vary depending on the export and import position if consumers can purchase goods over the Internet from the core as well as from peripheries, and e-commerce is traded in two directions.

assuming asymmetric regions, avoids tax-cut competition and realizes higher tax revenues. The finding that origin-based taxes generate larger tax revenues should be compared with the results presented by Bacache-Beauvallet (2018, Proposition 7) and Wang and Ogawa (2022, Corrigendum), although their models are quite different from ours. They showed that the sum of the tax revenues of two regions of different sizes is higher under a destination-based tax than under an origin-based tax, as the latter distorts consumers' choice of where to buy. In contrast, our model omits the consumer's choice of where to buy but instead includes a choice of how to buy, and the destination-based tax distorts that choice, leading to the opposite result.

These results are only insights based on numerical calculations; they are not the results of analytical solutions. Thus, what can be said about the nature of equilibrium in an environment with tax competition between asymmetric regions under the destination principle of e-commerce is that the expansion of e-commerce as online shopping costs fall generally intensifies competition to lower taxes and decreases regional tax revenue.

5.2 Equilibrium for online purchases only

Thus far, it has been assumed $e \geq 0$. This allowed us to depict a situation in which consumers buy goods from their own regions in brick-and-mortar stores. In this subsection, we analyze the situation in which consumers in region i will purchase not only good j but also good i online. This situation is derived by assuming $e < 0$. In this case, consumers have no choice regarding how they purchase; thus, the number of online users does not change when the tax rate or the cost of online purchases changes. Then, the fourth term in (27) is zero, and (28) and (30) can be rewritten as follows:

$$\left.\frac{\partial R_i^D}{\partial t_i^D}\right|_{t_i^D=t_j^D=t_i^{O*},e<0} = 0 \quad \text{and} \quad \left.\frac{\partial^2 R_i^D}{\partial t_i^D \partial e}\right|_{t_i^D=t_j^D,e<0} = \frac{\partial Q_i^D}{\partial e} = -\left(1-\frac{e}{\delta}\right) < 0.$$

The signs of these equations indicate that tax rates and tax revenues will be equal regardless of which tax principle is applied to e-commerce, which means that Propositions 2 through 4 will no longer hold. If consumers have no choice about how they buy goods and all goods are purchased online, no tax competition occurs because the tax base is not affected by changes in tax rates, even in the case of a destination-based taxation. Thus, the choice of the tax principle becomes irrelevant to the consequences of tax competition. Conversely, as indicated in Propositions 2 through 4, as long as consumers have the choice of how to purchase goods, it remains the case that tax principles should be applied that remain neutral to that choice.

6 Conclusion

This study has analyzed which of the two tax principles governments could apply to e-commerce to avoid the race to lower tax rates and achieve greater tax revenue. The distinctive feature of our approach compared with the previous tax competition studies is that we analyze that the different implications of the two representative tax principles have on tax competition when consumers are given a new choice of how to purchase goods instead of where to purchase goods. Goods purchased in brick-and-mortar stores are taxed under the origin principle, which is a form of taxation observed especially in transactions that cross city or state borders or between regions where no customs or other border adjustment mechanisms are in place. By contrast, the government may apply the origin principle tax or destination principle tax to e-commerce. This raises the question of whether the origin or destination principle should apply to online purchases.

We compared the tax competition equilibrium under two taxation principles and showed that applying origin-based taxation to both brick-and-mortar and online purchases mitigates the excessive tax reductions associated with tax competition and results in higher tax revenues. Furthermore, we showed that the expansion of the online market through the offer of lower online purchase costs raises the equilibrium tax rate in origin-based tax competition but lowers it in destination-based tax competition. Thus, the main argument emerging from our study is that, given that origin-based tax is applied to purchases of goods in brick-and-mortar stores, a move toward applying the destination principle when taxing online purchases may accelerate the race to lower the tax, while applying the same taxation principle to both brick-and-mortar stores and online purchases would curb tax competition. The destination principle taxation creates distortions because it incentivizes governments to induce their own consumers to shop online. If a consumer in one region buys a good in a brick-and-mortar store in a neighboring region, tax is paid to the neighboring region. However, if the consumer purchases goods online from the neighboring region, the tax can be paid to the home region. In addition, by encouraging consumers in neighboring regions to shift from online purchases to brick-and-mortar purchases of goods produced in their own regions, governments can increase their tax revenues. Consequently, under the destination principle of taxation on e-commerce, governments are in a race to steal other regions' tax bases by inducing their own consumers to buy online, leading to lower tax rates and revenues.

We derived key results from a symmetric tax competition model to simply present a new view of tax principles as they apply to e-commerce. In the second half of the study, the model was extended to two regions with different population sizes. This extension would be useful to confirm the robustness of the result that origin-based taxes on e-commerce are less distortive on consumer choice of "how to purchase" goods and to provide insight into the possibility that large and small regions have different preferences for the tax principles they apply. As for the former, we confirmed that the results under symmetric tax competition are generally valid. Given that the origin-based tax is applied to in-store purchases, applying the origin-based tax to e-commerce as well would avoid competition to lower tax rate. For the latter, Fig. 6b shows that given that both regions apply the same tax principles, there is a preference for an origin-based tax that generates higher tax revenues for any region. However, by shifting from the origin principle to the destination principle, the government can influence consumer choices by changing tax rates, thereby unilaterally expanding its tax base and increasing tax revenue. Any region, regardless of population size, has an incentive to shift to the destination principle of taxation, but smaller regions would have a stronger incentive to deviate from the adoption of the origin-based tax because they have a stronger incentive to lower tax rates and broaden their tax base, i.e., Kanbur and Keen (1993). Although the current model of asymmetric regions is difficult to solve analytically, such inferences suggest that regions have incentives to deviate from applying origin-based tax to online purchases of goods, especially in regions with smaller populations where the incentive to shift from the origin principle to the destination principle is stronger. In any case, however, because the adoption of any tax principle implicitly assumes the coordination of tax systems across regions, there is room to analyze the incentives that make this coordination possible.

Although our study provides some generalizations such as assuming situations in which demand is elastic with respect to the tax rate, it retains some specific assumptions. The first assumption is that the objective function of the government is to maximize tax revenue. This setting is used in many tax competition models. However, for further generalization, it may be necessary to change the government's objective. In such a case, we would need to adopt a different approach than solving the model analytically. Second, we assumed a competitive market and two independent goods. Although the case of one firm operating in each region with substitute goods has been analyzed by Aiura and Ogawa (2021), we may extend the analysis to more elaborate, imperfectly competitive e-commerce models. Our model allows for the inclusion of consumer purchases of goods online in the analysis, but it does not explicitly model platform companies that are dominant in the online market. Specifically, while the analysis focuses on tangible assets, it is increasingly important to discuss tax policy under a model in which semi-tangible assets such as data are traded online. Third, it is theoretically worthwhile to consider the case in which destination-based taxation is imposed on the purchase of goods in brick-and-mortar stores. Indeed, in some circumstances, it is costly but technically possible to apply the destination principle of taxation when making purchases at brick-and-mortar stores, and much research has been conducted in this regard (Haufler and Pflüger, 2004; Antoniou et al., 2019, 2022)[13] If the destination-based tax applies to the purchases of goods in brick-and-mortar stores in our model, based on the mechanisms leading to our results, applying the origin-based tax to the purchase of goods online would distort the choice of "how to purchase." Thus, a tax method in line with the tax principle applicable to purchases in brick-and-mortar stores might be applied to online purchases, resulting in the adoption of a destination-based tax on e-commerce.

[13] The US attempts to apply the destination principle through use taxes, but it is difficult to operate as intended, and *both the origin and destination principle coexist* (Agrawal et al., 2022).

Appendices

Appendix A

Figure 2a shows that q_{ij}^{OB} is the smallest for individual consumption; therefore, if $q_{ij}^{OB} > 0$ is shown, then all consumption is positive. Substituting $p_i = p_j = c$ and $t_i = t_j = t_i^{O*}$ into (9) yields

$$q_{ij}^{OB} = \frac{1}{2}\left(A - \frac{3}{2}e - \frac{e^2}{4\delta}\right) > \frac{1}{2}\left(A - \frac{3}{2}\delta - \frac{\delta^2}{4\delta}\right) = \frac{1}{2}\left(A - \frac{7}{4}\delta\right) > 0,$$

where the first sign is from Assumption 1, and the last sign is from Assumption 2. This suggests that the equilibrium quantity under origin-based taxation is positive for any e and x_{ij} under these two assumptions.

Appendix B

The first-order condition is expressed as follows: $\partial R_i^D / \partial t_i^D |_{t_i^D = t_j^D} \equiv f(t_i^D) = 0$. Subsequently, from (27), we obtain

$$f(t_i^D) = \frac{2}{\delta}\left(t_i^D\right)^2 - \frac{2}{\delta}[A + (2\delta - e)]t_i^D + 2\left(A - \frac{2\delta - e}{4\delta}e\right) = 0, \tag{34}$$

where $f(t_i^D)$ is a convex downward quadratic function with respect to t_i^D. The second-order condition is expressed as follows: $\partial^2 R_i^D / \partial (t_i^D)^2 |_{t_i^D = t_j^D} \equiv s(t_i^D) < 0$, where

$$s(t_i^D) = \frac{7}{\delta}t_i^D - \frac{4}{\delta}\left[A + \left(1 - \frac{e}{\delta}\right)\delta\right].$$

$s(t_i^D)$ is a monotonically increasing linear function. The solution to $s(t_i^D) = 0$ is denoted by t_i^S:

$$t_i^S = \frac{4}{7}\left[A + \left(1 - \frac{e}{\delta}\right)\delta\right].$$

If the solution satisfying $f(t_i^D) = 0$ is greater than or equal to t_i^S, then the second-order condition is not satisfied. Conversely, if the solution is less than t_i^S, it satisfies the second-order condition:

$$f(t_i^S) = -\frac{24}{49\delta}\left(A - \frac{8e - \delta}{8}\right)^2 - \frac{1}{8}\left[13 - 8\left(\frac{e}{\delta}\right) - 4\left(\frac{e}{\delta}\right)^2\right]\delta < 0,$$

indicating that t_i^S is between the two solutions satisfying $f(t_i^D) = 0$ because $f(t_i^D)$ is a convex downward quadratic function. Therefore, $f(t_i^D) = 0$ has two solutions, and only the smaller solution satisfies the second-order condition.

Appendix C

Because $\partial t_i^{D*}/\partial e = -[\partial f(t_i^{D*})/\partial, e]/[\partial f(t_i^{D*})/\partial t_i^{D*}]$, we derive the sign of $\partial f(t_i^{D*})/\partial e$ and $\partial f(t_i^{D*})/\partial t_i^{D*}$, respectively. From (34), we obtain:

$$\frac{\partial f(t_i^D)}{\partial t_i^D} = \frac{4}{\delta}t_i^D - \frac{2}{\delta}[A + (2\delta - e)],$$

which can be rewritten by substituting (29) as follows:

$$\frac{\partial f(t_i^{D*})}{\partial t_i^D} = -\frac{2\sqrt{A^2 - 2(A+\delta)e + 4\delta^2}}{\delta} < 0.$$

Next, from (31), if $t_i^{D*} > \delta/2$, then, we have

$$\frac{\partial f(t_i^D)}{\partial e} = \left.\frac{\partial^2 R_i^D}{\partial t_i^D \partial e}\right|_{t_i^D = t_j^D} > 0.$$

We now check whether $t_i^{D*} > \delta/2$ holds. From (34), tax revenue is maximized at t_i^{D*}; that is, $f(t_i^{D*}) = 0$, and thus, t_i^D satisfying $f(t_i^D) > (<) 0$ is smaller (larger) than t_i^{D*}. When we substitute $t_i^D = \delta/2$ in (34), we obtain

$$f\left(\frac{\delta}{2}\right) = \frac{e^2}{2\delta} + \left(A - \frac{3}{2}\delta\right).$$

As $A > 7\delta/4 > 3\delta/2$ from Assumption 2, we obtain $f(\delta/2) > 0$. This means that $t_i^{D*} > \delta/2$ is valid and, thus, $\partial f(t_i^D)/\partial e > 0$. Thus, $\partial t_i^{D*}/\partial e > 0$.

Appendix D

Substituting $p_i = c$, (1), (7), (8), and (9) into (13), we obtain the tax revenue of each government as follows:

$$R_0^O = 2\left\{A - \left[t_0^O + \frac{2(1-b)\delta - e}{4\delta}e\right]\right\}t_0^O \text{ and}$$
$$R_1^O = 2\left\{A - \left[t_1^O + \frac{2(1+b)\delta - e}{4\delta}e\right]\right\}t_1^O.$$

The first-order conditions for tax revenue maximization are as follows:

$$\frac{\partial R_0^O}{\partial t_0^O} = 2\left\{A - \left[2t_0^O + \frac{2(1-b)\delta - e}{4\delta}e\right]\right\} = 0 \text{ and}$$
$$\frac{\partial R_1^O}{\partial t_1^O} = 2\left\{A - \left[2t_1^O + \frac{2(1+b)\delta - e}{4\delta}e\right]\right\} = 0.$$

By solving these equations, we obtain (32).

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References

Agrawal, D. R. (2016). Local fiscal competition: An application to sales taxation with multiple federations. *Journal of Urban Economics, 91*, 122–138.

Agrawal, D. R. (2021). The Internet as a tax haven. *American Economic Journal: Economic Policy, 13*, 1–35.

Agrawal, D. R., & Fox, W. F. (2017). Taxes in an e-commerce generation. *International Tax and Public Finance, 24*, 903–926.

Agrawal, D. R., & Fox, W. F. (2021). Taxing goods and services in a Digital Era. *National Tax Journal, 74*, 257–301.

Agrawal, D. R., Hoyt, W. H., & Wilson, J. D. (2022). Local policy choice: Theory and empirics. *Journal of Economic Literature, 60*(4), 1378–1455.

Agrawal, D. R., & Mardan, M. (2019). Will destination-based taxes be fully exploited when available? An application to the US commodity tax system. *Journal of Public Economics, 169*, 128–143.

Agrawal, D. R., & Shybalkina, I. (2023). Online shopping can redistribute local tax revenue from urban to rural America. *Journal of Public Economics, 219*, 104818.

Agrawal, D. R., & Wildasin, D. E. (2020). Technology and tax systems. *Journal of Public Economics, 185*, 104082.

Aiura, H., & Ogawa, H. (2013). Unit tax versus ad valorem tax: A tax competition model with cross-border shopping. *Journal of Public Economics, 105*, 30–38.

Aiura, H., & Ogawa, H. (2019). Indirect taxes in a cross-border shopping model: A monopolistic competition approach. *Journal of Economics, 128*, 147–175.

Aiura, H., & Ogawa, H. (2021). *Does e-commerce ease or intensify tax competition? Destination principle vs. origin principle*. CIRJE-F-1169, University of Tokyo.

Alm, J., & Melnik, M. I. (2005). Sales taxes and the decision to purchase online. *Public Finance Review, 33*, 184–212.

Antoniou, F., Hatzipanayotou, P., Michael, M. S., & Tsakiris, N. (2022). Tax competition in the presence of environmental spillovers. *International Tax and Public Finance, 29*, 600–626.

Antoniou, F., Hatzipanayotou, P., & Tsakiris, N. (2019). Destination-based versus origin-based commodity taxation in large open economies with unemployment. *Economica, 86*, 67–86.

Bacache-Beauvallet, M. (2018). Tax competition, tax coordination, and e-commerce. *Journal of Public Economic Theory, 20*, 100–117.

Ballard, C. L., & Lee, L. (2007). Internet purchases, cross-border shopping, and sales taxes. *National Tax Journal, 60*, 711–725.

Beem, R., & Bruce, D. (2021). Failure to launch: Measuring the impact of sales tax nexus standards on business activity. *Journal of Public Economics, 201*, 104476.
Birg, L. (2019). *Cross-border or online: Tax competition with mobile consumers under destination and origin principle*. University of Göttingen working papers in economics 265.
Bruce, D., & Fox, W. F. (2000). E-commerce in the context of declining state sales tax bases. *National Tax Journal, 53*, 1373–1388.
Bruce, D., Fox, W. F., & Luna, L. (2009). State and local government sales tax revenue losses from electronic commerce. *State Tax Notes, 52*, 537–558.
Cavallo, A. (2017). Are online and offline prices similar? Evidence from large multi-channel retailers. *American Economic Review, 107*, 283–303.
Devereux, M. P., Lockwood, B., & Redoano, M. (2007). Horizontal and vertical indirect tax competition: Theory and some evidence from the USA. *Journal of Public Economics, 91*, 451–479.
Devereux, M. P., Lockwood, B., & Redoano, M. (2008). Do countries compete over corporate tax rates? *Journal of Public Economics, 92*, 1210–1235.
Einav, L., Knoepe, D., Levin, J., & Sundaresan, N. (2014). Sales taxes and Internet commerce. *American Economic Review, 104*, 1–26.
Ellison, G., & Ellison, S. F. (2009). Tax sensitivity and home state preferences in internet purchasing. *American Economic Journal: Economic Policy, 1*, 53–71.
Fox, W. F., Hargaden, E. P., & Luna, L. (2022). Statutory incidence and sales tax compliance: Evidence from Wayfair. *Journal of Public Economics, 213*, 104716.
Genser, B. (1996). Generalized equivalence property of the mixed International VAT regime. *Scandinavian Journal of Economics, 98*, 253–262.
Goolsbee, A. D. (2000). In a world without borders: The impact of taxes on Internet commerce. *Quarterly Journal of Economics, 115*, 561–576.
Goolsbee, A. D., Lovenheim, M. F., & Slemrod, J. (2010). Playing with fire: Cigarettes, taxes and competition from the Internet. *American Economic Journal: Economic Policy, 2*, 131–154.
Gutuza, T. (2010). Tax and e-commerce: Where is the source. *South African Law Journal, 127*, 328–338.
Hashimzade, N., Khodavaisi, H., & Myles, G. D. (2011). Country characteristics and preferences over tax principles. *International Tax and Public Finance, 18*, 214–232.
Haufler, A., & Pflüger, M. (2004). International commodity taxation under monopolistic competition. *Journal of Public Economic Theory, 6*, 445–470.
Haufler, A., Schjelderup, G., & Stähler, F. (2005). Barriers to trade and imperfect competition: The choice of commodity tax base. *International Tax and Public Finance, 12*, 281–300.
Hotelling, H. (1929). Stability in competition. *Economic Journal, 39*, 41–57.
Kanbur, R., & Keen, M. (1993). Jeux sans frontieres: Tax competition and tax coordination when countries differ in size. *American Economic Review, 83*, 877–892.
Keen, M., & Lahiri, S. (1998). Comparison between the destination and origin principles under imperfect competition. *Journal of International Economics, 45*, 323–350.
Lockwood, B. (2001). Tax competition and tax coordination under destination and origin principles: A synthesis. *Journal of Public Economics, 81*, 279–319.
Lockwood, B., De Meza, D., & Myles, G. D. (1994a). When are origin and destination regimes equivalent? *International Tax and Public Finance, 1*, 5–24.
Lockwood, B., de Meza, D., & Myles, G. D. (1994b). The equivalence between destination and non-reciprocal restricted origin tax regimes. *Scandinavian Journal of Economics, 96*, 311–328.
Lockwood, B., de Meza, D., & Myles, G. (1995). On the European Union VAT proposals: The superiority of origin over destination taxation. *Fiscal Studies, 16*, 1–18.
Miyatake, K., Nemoto, T., Nakahara, S., & Hayashi, K. (2016). Reduction in consumers' purchasing cost by online shopping. *Transportation Research Procedia, 12*, 656–666.
Nielsen, S. B. (2001). A simple model of commodity taxation and cross-border shopping. *Scandinavian Journal of Economics, 103*, 599–623.
OECD. (2001). *Consumption tax aspects of electronic commerce: A report from Working Party No. 9 on consumption taxes to the Committee on Fiscal Affairs.*http://www.oecd.org/tax/consumption/2673667.pdf.
Smith, M. D., & Brynjolfsson, E. (2001). Consumer decision-making at an Internet shopbot: Brand still matters. *Journal of Industrial Economics, 49*, 541–558.
Trandel, G. A. (1994). Interstate commodity tax differentials and the distribution of residents. *Journal of Public Economics, 53*, 435–457.

Wang, W., & Ogawa, H. (2022). Tax competition, tax coordination, and e-commerce: A corrigendum. *Journal of Public Economic Theory, 24*, 1591–1592.