WIDER Working Paper 2023/125

Double taxation treaties and resource revenue mobilization in developing countries

A neural network approach

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October 2023

United Nations University World Institute for Development Economics Research

wider.unu.edu

Abstract: Double taxation treaties, by assigning taxing rights to rival countries and thereby eradicating double taxation, aim to facilitate cross-border trade and investment. The eradication of double taxation is achieved through reductions in withholding tax rates on passive income in source countries, resulting in revenue losses. Multinational corporations structure their investments to benefit from treaty-reduced withholding tax rates, exacerbating the revenue losses. These phenomena are especially important in resource-rich countries, where international expertise and multinational corporations dominate the scene, posing challenges to revenue mobilization. This paper investigates the effects of double taxation treaties on resource revenue mobilization in 83 resource-rich countries from 2000 to 2019 by applying standard panel fixed effects and methods-of-moments approaches. We calculate countries' centrality indices by year on the basis of their importance in the tax treaty network and show that centrality indices have a negative relationship with resource revenue mobilization—findings that are robust to alternative centrality indices and government revenue aggregates. We use the betweenness centrality index to identify countries characterized as intermediate jurisdictions (countries with a betweenness centrality index above the median of countries in the network for each year independently), arguing that multinational companies structure their investments to benefit from the low withholding tax rates in these countries. Applying the entropy balancing method, we find evidence of a negative effect of signing tax treaties with country-classified investment hubs on resource revenue mobilization.

Key words: centrality indices, double taxation treaties, entropy balancing, resource revenue mobilization, withholding taxes

JEL classification: F21, F23, H26, Q32

Acknowledgements: Harouna Kinda is grateful to UNU-WIDER for the opportunity to conduct this research as part of the Visiting PhD Fellowship in Helsinki, April–June 2023. The authors are grateful to Nourat Guigma for research assistance and data curation, as well as to Ibrahim Nana and Grégoire Rota-Graziosi for insightful comments. The authors also thank participants in the UNU-WIDER seminar series.

Note: As the research is part of Harouna Kinda's PhD thesis, the authors will hold copyright to facilitate publication of the thesis.

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This study has been prepared in the context of the UNU-WIDER Visiting PhD Fellowship programme and is published within the UNU-WIDER project GRD – Government Revenue Dataset. It is part of UNU-WIDER's Domestic Revenue Mobilization (DRM) programme, which is financed through specific contributions by the Norwegian Agency for Development Cooperation (Norad).

Information and requests: publications@wider.unu.edu

ISSN 1798-7237 ISBN 978-92-9267-433-5

https://doi.org/10.35188/UNU-WIDER/2023/433-5

Typescript prepared by Joseph Laredo.

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1 Introduction

The importance of international taxation was underscored by global international corporate tax reforms under the Organisation for Economic Co-operation and Development/Group of Twenty (OECD/G20) Base Erosion and Profit Shifting (BEPS) Inclusive Framework (OECD 2021). The reforms were designed to address BEPS challenges to international taxation, as well as challenges linked to globalization and digitalization. However, they did not specifically seek to resolve international taxation challenges linked to bilateral tax treaties, although certain aspects of bilateral tax treaties will have to be updated in the light of the reforms. Bilateral tax treaties (hereafter BTTs) assign taxing rights between rival jurisdictions—usually between source and residence jurisdictions—on income from cross-border transactions.[1,2] They limit the ability of residence countries to tax their residents on their worldwide income (i.e. place restrictions on residence countries taxing foreign source income) and of source countries to tax income sourced by non-residents within their jurisdiction. In that sense, they may impact the amount of tax revenue source governments collect from transactions involving multinational enterprises (hereafter MNEs), as well as influence the amount of after-tax returns MNEs derive from their investments (Readhead and Taquiri 2021).

This study focuses on the impact of BTTs on extractives revenue mobilization in resource-rich countries. BTTs exacerbate international taxation challenges in the natural resources sector for three reasons: first, the unique nature of extractives/natural resources—the resources are finite and non-renewable, and they incur high sunk costs with long investment and recovery periods (Daniel et al. 2017)—necessitating the design of a special fiscal regime to capture a reasonable amount of the rents available. Since countries usually get only one chance to tax income arising from petroleum and mining extraction, huge tax treaty networks may rob resource-rich countries of the opportunity to collect an acceptable amount of rents. Second, the resource value chain is characterized by a more pronounced use of international expertise (inter alia, investors, service providers, licence holders, and suppliers), the providers of which are not residents in the source country (Readhead and Taquiri 2021). To contribute to the efficiency and equity of the mining fiscal regime and overall tax policy, it is important that these non-residents pay tax, although treaty withholding tax rates in source countries are typically much lower than statutory withholding rates.

Third, the international expertise is broadly reflective of the dominance of MNEs in the extractives sector (i.e. of the foreign investment required to develop and operate mining projects) across countries. As well as the expertise, MNEs have the financial and administrative wherewithal to engage in resource extraction in comparison with source governments and domestic investors (Albertin et al. 2021; Ndikumana and Sarr 2019). The involvement of MNEs can contribute

[1] Three types of jurisdiction are considered important here: source countries, residence countries, and intermediate countries. Source countries are those where income is earned (in a natural resources context, they are countries where a mine or petroleum rig is located) and typically consist of (net) capital-importing developing countries. Residence countries are where multinational enterprises are headquartered and are typically (net) capital-exporting developed countries. Intermediate countries are those through which investments are routed, typically tax and investment hubs. These offer light taxation—low corporate income and other profit taxes, no taxes on the transfer of assets or capital gains, and territorial tax systems—and other preferential regimes, making them attractive (Albertin et al. 2021; Beer and Loeprick 2021; Lejour 2021). Investment hubs differ from tax hubs. The OECD defines investment hubs as those through which investments are routed, with total inward FDI-to-GDP ratios of over 150 per cent. Additionally, the primary role of investment hubs is to minimize the effective tax rate on cross-border capital (Baistrocchi 2023). On the other hand, tax hubs have FDI-to-GDP ratios of less than 100 per cent.

[2] In this paper we use the terms tax treaty, bilateral tax treaty (BTT), and double taxation treaty (DTT) interchangeably.

significantly to source governments' revenues, specifically through tax (e.g., corporate income taxes, withholding and capital gains taxes, value added tax, and even payroll taxes) and non-tax regimes (e.g. royalties and bonuses). The contributory role of MNEs, however, is eroded by the prospects of MNEs engaging in profit shifting and other aggressive tax optimization techniques, which result in huge revenue losses. The revenue losses are exacerbated by the prevalence of (inefficient and ineffective) tax incentives granted to mining MNEs in source countries (Coulibaly and Camara 2022; Readhead 2018).[3,4]

The primary rationale for signing a BTT is to attract foreign direct investment (FDI) to boost economic development (and potentially expand the tax base and increase revenue mobilization), although the empirical evidence on that effect is mixed (Baker 2014; Barthel et al. 2010; Janeba 1995; Neumayer 2007; Shah and Qayyum 2015).[5] Davies (2003) finds that BTTs have no positive impact on inward or outward FDI, while Hines (2000) shows that tax treaties may actually reduce investment in developing countries. Differentiating between new and old treaties (i.e. treaties concluded after/before 1981), Blonigen and Davies (2004) analyse the impact of BTTs on FDI. While they corroborate the findings in Davies (2003), they show that treaties can positively impact FDI in developing countries. Blonigen and Davies (2005) find that recent BTTs do not encourage new investment and may even reduce investment. They argue that these treaties are intended to reduce tax evasion rather than promote FDI. In distinguishing between relevant and irrelevant tax treaties, Petkova et al. (2020) find that only treaties that offer investors a financial advantage over domestic law increase FDI. In contrast, treaties that do not offer financial advantages have no impact on FDI.

While the attraction of FDI and reduction of double taxation have been espoused as the main benefits of signing a tax treaty, other benefits abound. In principle, the benefits from the source country's perspective can differ from those for the investor (i.e. the residence country). For the source country, the benefits include improved inter-state cooperation in tax enforcement, especially through the exchange of information (McGauran 2013); increased administrative capacity from technical assistance meant to improve compliance and detect international tax avoidance and evasion (Blonigen and Davies 2002); and positive network externalities for countries that are members of the BTTs with developed countries (Baistrocchi 2008). From the investor's perspective, the benefits include increased tax and legal certainty, less risk of double taxation, elimination of discriminatory treatment, and the prevention and/or resolution of disputes in relation to double taxation (IMF 2023b; Readhead and Taquiri 2021).

Nevertheless, there are significant attendant costs of signing BTTs, the most important of which are losses of tax revenue and aggressive tax optimization through exploiting the network of BTTs to minimize tax bills. The losses in tax revenue occur because BTTs restrict source countries' taxing rights through reductions in withholding tax rates on dividends, interest, and royalties; restrictions on source countries' taxing rights on some business profits (specifically those deriving from technical and professional/management fees) and limitations on the taxation of capital gains,

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[3] Coulibaly and Camara (2022), using data for 16 countries over the period 2003–15, show that cuts in the statutory corporate income tax rate for mining companies do not attract FDI to gold and silver projects in Africa.

[4] The mining tax incentives can be incorporated into (i) the general tax code, i.e. the benchmark fiscal regime (e.g. reduced corporate income tax rates); (ii) the mining code (e.g. reduced rates on imported goods for mining); and (iii) individual or project-by-project mining contracts (e.g., corporate income tax holidays, royalty holidays, and other tax exemptions for a defined period). The incentives are typically locked in onerous fiscal stabilization clauses with poorly designed fiscal terms.

[5] See Appendix 5 of IMF (2014), Quak and Timmis (2018), and Shehaj and Zagler (2023) for a summary of the empirical discussion on the relationship between BTTs and FDI.

including those from offshore sales of shares and assets in companies (Hearson 2018; Millán-Narotzky et al. 2021). If source countries applied withholding taxes at the prevailing statutory rates, they could reduce the amount of revenue loss from profit shifting. Given the restriction of source countries' rights discussed above, however, the extent to which a treaty can be exploited by MNEs exacerbates revenue losses. Treaty shopping—which consists of structuring corporate activities to benefit from tax treaties or specific aspects of tax treaties across different jurisdictions—has also increased the difficulty of effectively taxing flows to parent companies (IMF 2014). It involves setting up subsidiaries (shell companies) in jurisdictions that have signed advantageous BTTs with target jurisdictions (i.e. resource-rich source countries) and channelling investments and associated payments through those countries and other low-tax jurisdictions.

Our paper focuses on the impact of BTTs on resource revenue mobilization in 83 resource-rich countries covering the period 2000–19. The paper makes four key contributions to the literature. First, we contribute to the empirical literature estimating the revenue impact of BTTs (Balabushko et al. 2017; Beer and Loeprick 2021; Hearson 2018; Janský and Šedivý 2019; Janský et al. 2021). Most of these papers estimate revenue forgone from tax treaties (where withholding tax rates on passive incomes in tax treaties are lower than those that otherwise apply) or revenue elasticities (i.e. the proportionate change in a specific passive income given a change in the given withholding tax rate). Our paper differs from most of the above since we do not provide granular country-level estimates, but only high-level directions of effects (like Beer and Loeprick 2021). Focusing on the natural resources sector, ours is the first in-depth study on the impact of BTTs on resource revenue mobilization in resource-rich countries. Applying standard panel fixed effects and system generalized method-of-moments (GMM) techniques to accommodate potential reverse causality and simultaneity between BTTs and revenue mobilization, we find that BTTs have a strong negative impact on both domestic resource revenue and total government revenue, and a weaker relationship with non-resource revenue.

Second, we contribute to the literature on measures attempting to quantify BTTs (Millán-Narotzky et al. 2021; Tax Justice Network 2021), employing a novel approach based on the centrality of BTTs' neural networks using network theory (Hong 2018; Nakamoto and Ikeda 2018). The effect of BTTs has typically been quantified by using binary variables and measures of tax treaty aggressiveness. Unlike studies that use a dummy variable to model the existence of a BTT in a source country or multiple BTTs between countries (Beer and Loeprick 2021), those using measures of aggressiveness quantify the ability of a specific country to secure lower withholding taxes from another country in a tax treaty (Tax Justice Network 2021). We follow a different approach, focusing on centrality indices applied in network theory. Centrality indices do not capture aggressiveness per se but focus on the role of the number of networks of tax agreements by groups of countries and the relative importance of each agreement in the set of connections. The indices permit measurement of a country's direct connection to other countries in the treaty network, as well as possible indirect connections (i.e. countries that serve as intermediate jurisdictions). Our primary measure of centrality, the degree centrality index, is based on the number of BTTs a country has within the full treaty network. For impact evaluation, we employ the betweenness centrality index, which captures the closeness of a country to others indirectly or when a specific country is the shortest possible distance between other countries (i.e. in cases where a country serves as a key broker between other countries).

Third, we follow a data-driven approach in estimating the resource revenue impact of signing a tax treaty with an investment or tax hub (coded using the betweenness centrality index) by employing an impact evaluation method. We use the median (the values are similar to the first quartile) and third quartile of the betweenness index to split countries between high and low betweenness centrality, with the countries above the threshold classified as investment hubs with whom countries sign tax treaties (i.e. potential intermediate jurisdictions with many tax treaties,

perpetuating treaty shopping). We then employ the entropy balancing method (Hainmuller 2012) to estimate the effect of signing a BTT with an investment hub, where signing a treaty with an investment hub is considered treatment.[6] The method permits identification of the impact of BTTs on resource revenue mobilization by comparing countries that signed a BTT with an investment hub (treatment countries) with countries that did not (control countries) but have similar characteristics to the treatment group, while controlling for country-fixed effects and time effects. Our impact evaluation analysis complements that of Beer and Loeprick (2021) but differs in one key dimension: while their paper focused on BTTs between sub-Saharan African (SSA) countries and a predetermined investment hub (Mauritius), our paper takes a broader dimension in considering all potential investment hubs in the sample. Our findings corroborate the baseline results, with BTTs negatively impacting resource revenue mobilization. The findings are robust to different specifications and dynamic effects.

Fourth, we analyse the primary channel(s) through which BTTs affect resource revenue mobilization in source countries. As discussed in the Introduction, the revenue gains induced by signing a tax treaty can be linked to increased foreign investment, while revenue losses occur through restrictive permanent establishment rules, withholding tax restrictions, and limitations on the ability to collect capital gains taxes, all of which are exacerbated by treaty shopping. Without cross-country data on revenues from withholding and capital gains taxes over the sample period, we focus on FDI as the primary transmission channel through which BTTs influence (resource) revenues in source countries. We use the same treatment variable as above to ascertain the effect of signing a tax treaty with an investment hub on FDI inflows in resource-rich source countries. We find that BTTs have a positive, albeit marginal, impact on FDI through tax savings provided by the tax treaty generating additional investment. The findings, however, are non-robust.

The rest of the paper is organized as follows. Section 2 reviews the literature on estimates of the revenue costs of signing tax treaties. Section 3 provides a conceptual framework, focusing on the perceived importance of signing a tax treaty and the mechanisms through which a tax treaty erodes (resource) revenues in source countries. Section 4 presents the data and constructs the primary measures of tax treaty centrality. Section 5 outlines the empirical strategy. The results and robustness checks are presented in Section 6. Section 7 presents impact evaluation estimates of signing tax treaties with investment hubs and several sensitivity checks, including analyses of transmission channels. Section 8 concludes.

2 BTTs, tax incentives, and domestic revenue mobilization

There is a dearth of studies on the impact of BTTs on revenue mobilization across countries. The empirical literature falls into one of two types: country-specific estimates of revenue elasticities and revenue forgone, and cross-country regressions including some measure of BTT presence among the determinants of domestic revenue (most studies use a binary variable of BTT signing between countries). McGauran (2013) estimates revenue losses from developing countries signing BTTs with conduit countries with large bilateral tax treaty and investment networks (the paper focuses on the Netherlands), as well as other attractive aspects of fiscal regimes. The author finds that lower withholding tax rates on dividends and interest resulted in revenue losses of €771 million in 2011, with Venezuela, Brazil, and Kazakhstan losing most in absolute terms (relative to GDP,

[6] The method has been used increasingly in the literature, for example in assessing the impact of coups on the cost of debt (Balima 2020), the impact of IMF programmes (Balima and Sy 2021), the impact of sovereign debt default on inequality (Apeti 2023), and the impact of mobile money adoption on taxation (Apeti and Edoh 2023).

both Kazakhstan and Serbia lost more). Weyzig (2013) carries out similar analyses focusing on the determinants of treaty shopping (diverting or rerouting FDI through conduit countries that have a favourable treaty network). The author finds that BTTs are a key determinant of treaty shopping through the Netherlands, partly driven by lower dividend withholding tax rates.

ActionAid (2016) analyses two categories of revenue losses incurred by BTTs, namely lower withholding tax rates on dividends and interest payments. The highest tax losses, overwhelmingly from dividends, are registered by Philippines and Pakistan, as well as Mongolia (0.17 per cent of GDP). The losses are driven mostly by investments from the Netherlands, Switzerland, and Singapore. ActionAid (2016) shows that in 2013 Bangladesh lost approximately $85 million from just a single clause in its treaties that restricted its right to tax dividends, while the IMF (2014) finds that, in 2010, US tax treaties resulted in a $1.6 billion revenue loss in their non-OECD country counterparts.

Janský and Šedivý (2019) estimate the revenue losses from BTTs in 14 SSA and Asian developing countries. Focusing on dividends and interest payments in 2015, the authors show that revenue forgone is non-negligible. Philippines loses most—to the tune of over $500 million—amounting to 0.2 per cent of GDP. Mongolia also loses approximately 0.2 per cent of GDP, although the volume is considerably smaller ($19.9 million). Janský et al. (2021) estimate revenue elasticities, using 65,000 annual country–year observations covering the period 2009–16 and incorporating the effects of the EU Parent–Subsidiary and Interest and Royalties Directives (a guideline which reduces withholding tax rates among all EU members and Switzerland to zero). They find that dividend flows are highly elastic: i.e. a change in withholding tax rates results in a more than proportionate change in dividend flows. While interest flows are themselves highly elastic, the results are not robust.

Balabushko et al. (2017) use Ukrainian administrative data to estimate the sensitivity of specific outbound payments at an aggregate level—dividends and interest and royalty payments—and show non-negligible revenue costs of tax treaties, especially for outbound flows into major investment hubs. However, they conclude that the high elasticity of income flows suggests that increases in withholding tax rates at the individual treaty partner level do not necessarily result in more revenue collection. Beer and Loeprick (2021) use a sample of 41 African countries from 1985 to 2015 and a difference-in-differences framework to show that SSA countries that had signed a BTT with an investment hub (in their case, Mauritius) faced reductions in corporate tax revenue (up to 15 per cent of corporate income tax), with no attendant increase in FDI (consistent with the idea that BTT conclusion, rather than leading to an increase in nominal investment, results in the rerouting of income and investment flows, which potentially increase profit shifting). Treaty shopping drives some of the results, with increases in nominal investment flows and lower tax revenue (amounting to a loss of 5 per cent of corporate income tax).

BTTs can be used as an instrument for (or exacerbate the effects of) tax competition across countries in two ways: first, through the standard 'race to the bottom' of withholding tax rates being experienced across regions. The IMF (2014) shows that treaty withholding tax rates on dividends, interest, and royalties have fallen considerably since the 1980s. Countries with large treaty networks are disadvantaged because a reduced withholding rate with one treaty partner increases pressure to grant favourable withholding rates to other treaty members (Albertin et al. 2021). Second, through treaty shopping. By structuring corporate activities to benefit from BTTs or specific aspects of BTTs with low-tax jurisdictions (i.e. routing investments through low-tax conduit countries), international businesses extract income in forms that attract low or zero withholding tax rates. Hong (2018), by conceptualizing and measuring the direct and indirect routes MNEs use to minimize taxation under BTTs, shows that treaty shopping results in considerable revenue losses through its impact on tax reductions on dividends.

3 Conceptual framework

3.1 Why sign BTTs?

Bilateral tax treaties, by splitting taxing rights over income and transactions arising from cross-border investments, are concluded to eliminate double taxation and protect against tax avoidance. In signing a BTT, the source country gives up some of its taxing rights in exchange for more FDI, better access to knowledge-based capital with positive spillovers, lower investment costs, and possibly non-tax benefits (IMF 2017, 2018). These treaties can be useful in ensuring certainty of the tax treatment of cross-border investment flows, the absence of which may result in overlapping taxing rights on the same income across jurisdictions and consequently in double taxation.[7]

The limitation of taxing rights may gain importance depending on a signatory country's importance to the global economy (as proxied by the amount of capital, i.e. the FDI, they route). The empirical literature shows that such FDI asymmetries can be crucial to how much revenue countries can generate while tied down by BTTs (Hearson 2018; Millán-Narotzky et al. 2021; Shehaj and Zagler 2023). Source countries are typically net capital-importers (countries where inward investment profits are sourced) while residence countries tend to be net-capital exporters (countries from which outward investment emanates). For BTTs between jurisdictions with equal economic relations, the limitation of taxing rights will be equally divided. However, for BTTs between countries with asymmetric FDI positions, the limitation of taxing rights represents significant revenue losses. This is especially true in resource-rich countries due to their dependence on FDI and finance sourced from outside the country, limited economic diversification, and an overall lack of technology and services for extractive industry projects.

BTTs are negotiated by governments, which use Model Tax Conventions as the basis for negotiation. The bulk of tax treaties are based on the OECD (OECD 2019) and the UN Models (UN 2018).[8] While there are fundamental similarities between the model texts, the OECD model grants more taxing rights to MNEs (hence, more taxing rights to the residence countries) since it was drafted primarily to eliminate double taxation and reduce source countries' taxing rights (Readhead and Laquiri 2021; Whittaker 1982). If adopting the OECD model cedes substantial taxing rights to residence countries, it questions the motives of source countries in signing asymmetric BTTs, with two key reasons advanced by the literature (Baistrocchi 2008). First, developing countries sign BTTs with residence countries to benefit from the positive network externalities derived from a tax treaty network.[9] Second, the prisoner's dilemma among developing countries forces them to sign BTTs: i.e. since developing countries are dependent on capital import, they fear driving away FDI to competing jurisdictions, which lends itself to the use of tax incentives and treaty shopping. In addition, relevance to the global economy—in that the source countries have alternative sources of revenue, due to their interconnections with other countries—is important for countries in negotiating BTTs (Baistrocchi 2008). The treaty network of a given source country will be closer to the UN model (hence, more taxing rights for the developing country) or OECD model depending on its relevance to the global economy.

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[7] Double taxation occurs when a taxpayer is required to pay taxes on the same income or assets in more than one jurisdiction.

[8] There are also regional models, such as the African Tax Administration Forum (ATAF) model.

[9] These include the minimization of enforcement and communication costs, as well as an increase in reputational advantages.

3.2 How do BTTs influence domestic (resource) revenue?

Assuming that tax treaties do indeed increase FDI, the treaties will indirectly contribute to domestic revenue mobilization by expanding the corporate income tax base (i.e. by taxing profits). In addition, FDI is an economic opportunity that stimulates job creation (hence more payroll taxes), boosts productivity through transfer of capital and technology, as well as stimulating economic growth (Damgaard et al. 2019). All these should expand the tax base, hence more direct and even indirect taxes.

BTTs limit taxing rights and result in revenue losses in three ways. First, they limit the definition of permanent establishment. Jurisdictions can tax business profits of an MNE only if the foreign company has a 'permanent establishment' in the country where the income arises.[10] While the concept of permanent establishment is straightforward in the extractives sector—given that natural resources are location-specific, MNEs cannot operate in the sector without permanent establishment—there are issues related to the taxation of specific services within the mining value chain, which an MNE's corporate structure can exploit (especially those provided by subcontractors). For example, inter-company management, as well as accounting, legal, and technical services, which are very important in the extractives sector, are not included under permanent establishment. Most tax treaties prevent source countries from levying withholding taxes on payments made to these service entities in return for their services.

Second, BTTs set upper bounds on withholding tax rates on outbound payments of passive income, specifically dividends (both portfolio and participating), royalties, interest, and service fees. Jurisdictions publish statutory rates for each category, and preferential treatment, in the form of reduced rates, is given to BTT partners.[11] Arguments for reducing source taxation have been espoused, including attracting more FDI, reducing the cost of assessing intangible property rights, and reducing costs for domestic businesses (Brooks and Krever 2015). However, BTTs significantly reduce these rates in comparison with domestic law, exacerbating tax optimization schemes by MNEs, who engage in treaty shopping (IMF 2018).

Third, BTTs limit source countries' rights to tax offshore indirect sales of shares or comparable interests in mining assets located in their countries (Albertin et al. 2021): i.e. the countries' ability to tax offshore indirect capital gains, which can be important in the extractives sector (IMF 2023b).[12] While most countries are able to direct the transfer of assets in their jurisdictions, the offshore transfer of assets is more difficult to tax (IMF 2014). MNEs can deliberately structure their transactions to fall outside the source countries' jurisdiction by selling mining assets in an offshore company holding the mining assets.

The restriction of taxing rights on withholding taxes and capital gains, and the ensuing revenue loss, is exacerbated by treaty shopping by MNEs. By structuring corporate activities to benefit from BTTs or specific aspects of BTTs with low tax jurisdictions (i.e. routing investments through low-tax conduit countries or tax hubs), international businesses extract income in countries that attract low or zero withholding tax rates. This may be the case for passive incomes—such as

[10] It is important to note that a BTT enforces or overrides a tax that has been incorporated into domestic law. This means that BTTs themselves cannot create new tax liabilities: that is the purview of domestic tax legislation.

[11] These data are available in the public domain through PricewaterhouseCoopers's World Tax Summaries.

[12] The importance of taxing indirect transfers of mineral assets is evident in Mozambique, where such taxes brought in significant sums of corporate income tax in 2017 and 2019 (IMF 2023a). Withholding taxes on payments to non-resident service and finance providers also contributed significantly to increases in corporate income tax.

royalties or management fees—that source countries find particularly difficult to value (IMF 2014). Arel-Bundock (2017) shows that the proliferation of BTTs allows MNEs to engage in treaty shopping, reducing source countries' fiscal autonomy and forcing them to react by maintaining lower withholding tax rates.

Given the above arguments, we ask the following questions:

1. Does a resource-rich (source) country's sheer number of agreements (BTTs) within the number of available treaties (i.e. degree centrality) reduce resource revenue mobilization?

2. Does signing a BTT with intermediate jurisdictions (i.e. countries classified as investment or tax hubs), hence encouraging treaty shopping, reduce revenue mobilization in source countries?

With regard to Q1, we posit that countries with many BTTs within the network will experience lower resource revenue mobilization due to the erosion of withholding tax rates and the aggressive tax optimization by MNEs through profit shifting. We offer two reasons for this. First, withholding tax rate differentials—the difference between the domestic statutory withholding rate and the BTT withholding rate on a specific passive income—are bound to be lower for countries with more BTTs (Janský et al. 2021). Hence, the potential revenue losses from signing BTTs may be smaller, invisible to the median voter and more politically justifiable. Second, it may also be the case that countries with lower withholding tax rates depend less on corporate income taxes, hence also less on withholding taxes, so they sign more tax treaties (Hearson 2018). Withholding taxes are levied on gross income payments to foreign entities and levied to backstop corporate income tax, thereby protecting the domestic tax base from possible tax avoidance. Countries that depend less on corporate income tax may also have lower withholding tax rates (the latter cannot be applied at exorbitantly high rates, lest they significantly dampen cross-border income and investment flows).

Essentially, Q2 gauges the revenue impact, in source countries, of tax treaty shopping. Our intuition is that tax optimization is cost-effective, and investors will seek out indirect routes (through conduit states) that maximize their tax savings. As a result, MNEs tend to locate their pass-through subsidiaries in countries that give them access to huge and favourable tax treaty networks that can easily be exploited.[13,14] These are typically intermediary countries that tax income minimally by applying low statutory rates (sometimes zero rates) to passive and corporate income, in addition to preferential regimes and territorial tax systems. They also contain treaties with low to zero withholding tax rates with source countries, as well as potentially not having any withholding taxes on their outbound payments (Albertin et al. 2021; Baistrocchi 2023; Beer and Loeprick 2021).[15]

We suggest three reasons for this. First, the proliferation of tax treaties results in insidious treaty shopping, constraining source governments' fiscal autonomy. The source governments, worried by MNEs' ability to escape taxes on their cross-border payments, respond by maintaining lower

[13] To reduce their tax burden, firms interested in investing abroad indirectly will locate their subsidiaries in conduit countries that give them access to overlapping tax treaty and investment treaty networks. Due to this overlap, subsidiaries that allow their parent company access to a tax treaty with the host government will often give the same parent company access to an investment treaty with the host government (Thrall 2021).

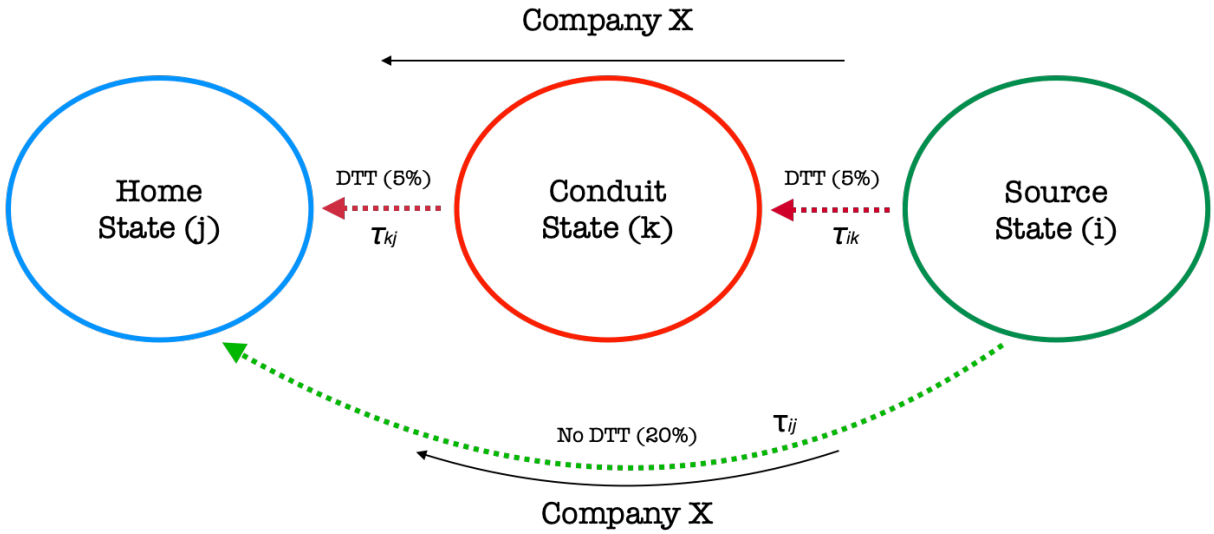
[14] This is exacerbated by the absence of anti-abuse measures—specifically Limitation on Benefits (LoB) provisions and 'beneficial ownership' rules—to reduce the risk of treaty shopping.

[15] Theoretically, countries with lower withholding taxes are more receptive to all types of foreign investment (greenfield FDI, mergers and acquisitions, and phantom FDI).

withholding tax rates (Arel-Bundock 2017), thus maintaining a negative cycle of low withholding tax rates. Second, and linked to the first point, is the prisoner's dilemma driving low source country withholding tax rates. Source countries fear driving FDI to competing jurisdictions, so they reduce their own withholding tax rates (Baistrocchi 2008). Third, treaty shopping can be especially detrimental when MNEs channel their international transactions through investment or tax hubs (with the minimal taxation and large treaty networks the latter provide), exacerbating profit-shifting risks.

Figure 1 presents a hypothetical case where Company *X* wishes to transfer capital from its subsidiary in the source country to its country of residence.

Figure 1: Bilateral withholding tax rate network



Source: authors' construction.

If the source and residence countries do not have a tax treaty in place, an outbound payment between the two states costs Company *X* a 20 per cent withholding tax. However, there may be a third country—an intermediate state, country *k*—with which the source and residence countries each have a BTT, such that transfers from the source country to the intermediary, and from the intermediate state to the residence country will be taxed at a reduced rate of 5 per cent. Formally, the objective function of Company *X* is to minimize the effective withholding tax rate for each source–residence–intermediary triplet *ijk*, i.e. on transfers made from source country *i* to residence country *j* indirectly through intermediate country *k*: $Min\ (WHT_{ijk}^{X}) = \tau_{ik} + \tau_{kj}(1 - \tau_{kj}) - \tau_{ij} < 0$. Company *X* could thus reduce its effective withholding tax burden from 20 per cent to 9.75 per cent, a cost economy of 10.25 per cent [0.05+(1-0.05) (0.05)-0.2 = -10.25%], by investing indirectly through a subsidiary set up in the intermediate jurisdiction and taking advantage of the lower-cost indirect route created by a tax treaty network.

4 Data and construction of centrality indices

4.1 Data

The sample comprises an unbalanced panel of 83 resource-rich developing countries covering the period 2000–19, focusing on countries with a resource rents-to-gross domestic product (GDP) ratio above 5 per cent. Our data on taxation are obtained from the Government Revenue Dataset (GRD) (UNU-WIDER 2023). Given that this paper focuses on the impact of BTTs on revenue

from the extractives sector, the dependent variable is total natural resources revenue. It comprises both tax (e.g., corporate income tax, value-added tax, and withholding taxes) and non-tax revenue (e.g. royalties on extractive activities, as well as licences and fees) in the extractives sector. We also use other measures of domestic revenues for sensitivity analysis: non-resource revenue, direct taxes (total taxes on income, profits, and capital gains), corporate income taxes (CIT), personal income tax (PIT), and total government revenue (all as shares of GDP).[16,17]

The independent variable of primary interest is the degree centrality index, calculated from adjacency matrices of double taxation treaties between countries (as discussed in Section 3). The index ranges from 0 to 1, higher values representing more centrality (i.e. the presence of more tax treaties in the source country). To facilitate the interpretation of results, we multiply the degree centrality index of double taxation treaties by *n-1* to render it in units. Data on BTTs are obtained from the ICTD's Source Index dataset, which itself builds on International Bureau of Fiscal Documentation (IBFD) data. The dataset contains information on signatory countries, the date of signature, and the date of entry into force of the agreement.[18] For the robustness analysis, we include the cumulative degree centrality, eigenvector centrality, betweenness centrality, closeness centrality, and farness centrality indices.

Control variables are chosen following the literature on determinants of (resource) revenue mobilization, distinguishing between economic variables and governance variables (Bornhorst et al. 2009; Crivelli and Gupta 2014). The economic variables include GDP per capita in constant 2015 US$, resource rents (% GDP), inflation (CPI, % annual), trade openness (% GDP) and net FDI inflows (% GDP). GDP per capita is a measure of the level of development and a proxy for tax administration and compliance capacity. More developed countries are expected to raise more tax revenue than developing countries due to more efficient and stronger tax administrations, as well as higher degrees of administrative sophistication (Crivelli and Gupta 2014). The impact of resource rents on taxation has been extensively studied, with no consensus view on the direction of effects. While earlier studies posited a positive relationship through resource rents generating a taxable surplus, more recent studies have posited a crowding-out effect through resource rents eroding incentives to invest in developing fiscal capacity (Crivelli and Gupta 2014). The effect is, thus, ambiguous. The impact of inflation on tax revenues is also expected to be ambiguous. The positive effect may be driven by changes in tax brackets and thresholds for income tax and VAT (Beer et al. 2023), while the negative effect is driven primarily by seigniorage.

Trade openness measures the volume of international trade in GDP, with an increase in trade conducive to taxation through its ease of collection (i.e. for VAT and excise taxes on imports), as well as through increased domestic consumption and corporate profits (Gnangnon and Brun 2019). In principle, trade openness is a proxy for the level of economic activity in a country. However, in the context of trade liberalization efforts—that is, a reduction of tariffs, as well as other trade taxes and non-tariff barriers to trade—an increase in trade openness would be associated with lower government revenue. FDI is expected to have a positive impact on resource revenue mobilization. Camara (2023) shows that these effects could be through increased job creation and productivity (hence, increased personal and corporate income taxes), as well as more

[16] See Oppel et al. (2021) for a more in-depth description of the variables.

[17] Since the descriptive statistics mostly include averages of aggregates over the entire sample period or averages per year, all 83 countries are included. However, our main data sources have missing values, which significantly reduces the number of countries during estimations.

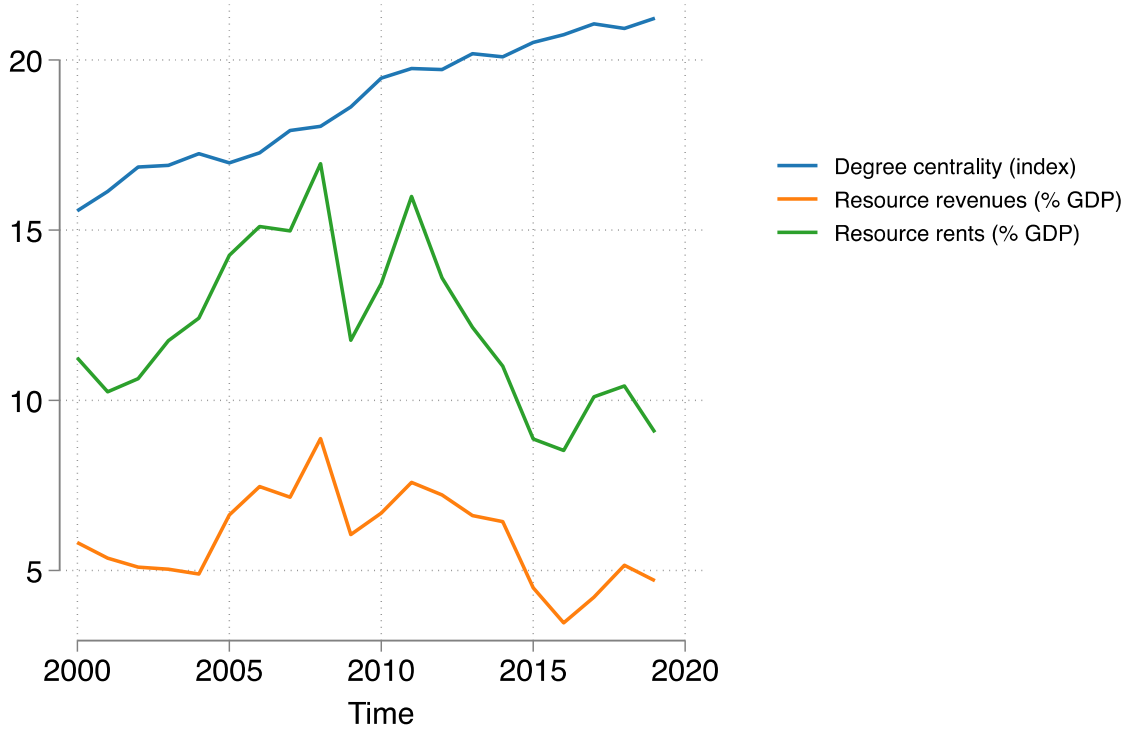
[18] To generate the centrality index, we implement an algorithm in STATA that facilitates the construction of adjacent matrices.

trade and consumption (hence, increased VAT and customs duties). However, negative effects of FDI may abound due to tax incentives and other preferential regimes for MNEs and aggressive tax optimization, as well as MNEs crowding out domestic local companies (Camara 2023; Readhead 2018).

The institutional variables are the control of corruption index from the World Governance Indicators (WGI) and political risk indicators from the International Country Risk Guide (ICRG). The control of corruption index ranges from -2.5 to 2.5, with higher values indicating better institutional quality (i.e. lower corruption). The ICRG indicators used are democratic risk (ranging from 0 to 6), external conflict risk (ranging from 0 to 12), socioeconomic conditions risk (ranging from 0 to 12), and investment profile risk (ranging from 0 to 12). For ICRG data, higher values indicate a low risk of institutional quality. All these variables measure institutional quality in source countries and are expected to have a positive relationship with (resource) revenue mobilization. The list of included countries and summary statistics, as well as definitions and sources of the variables, can be found in Tables A1 and A2 in Appendix A.

Figure 2 shows the evolution of the average degree centrality index, resource rents (% GDP), and resource revenues (% GDP) over the sample period.

Figure 2: Evolution of main variables over time

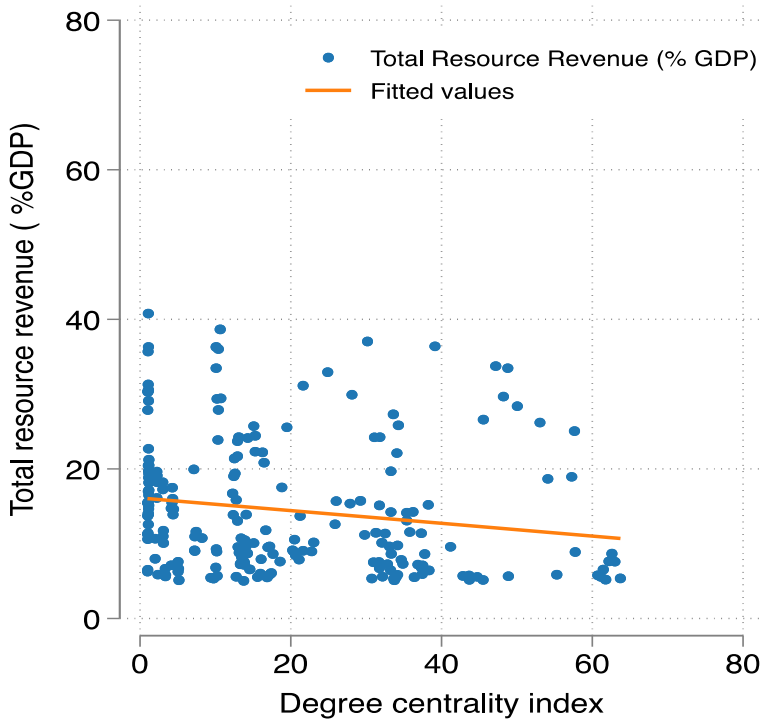


Source: authors' construction using GRD and ICTD Source Index Dataset.

The steady increase in resource rents and resource revenue up to 2008 and after 2009 was driven by an increase in commodity prices (most of the resource-rich countries in our study are commodity exporters), which culminated in the commodity super-cycle, the end of which resulted

in reduced resource revenue receipts.[19] The number of BTTs, however, has consistently risen over the sample period, reflecting the burgeoning, then entrenched role of globalization and the interconnectedness it fosters. Figure 3 shows a bivariate scatter plot between resource revenue mobilization and the degree centrality index, over the entire sample period. There is a clear negative correlation between the degree centrality index (number of treaties for a source country) and extractives sector revenues. Instead of being an incentive for increased FDI and, therefore, additional resources for resource-rich countries, double taxation treaties (DTTs) appear to be a setback for tax revenue mobilization. The exploratory analysis is stylized and excludes other mediating factors but shows that bilateral tax treaties can be associated with lower resource revenue mobilization.

Figure 3: Bivariate relationship between BTTs and resource revenue mobilization



Source: authors' construction using GRD and ICTD Source Index Dataset.

4.2 Generation and analysis of centrality indices

Social network analysis provides a powerful set of quantitative measures for understanding networks and the individuals and groups within them. Centrality indices identify a network's or graph's most important vertices and nodes, with the most important or central nodes assigned the highest values.[20] They offer alternative perspectives on the role of each country, or group of countries, in the internal network connections, showing how countries can minimize international tax bills by exploiting tax agreements. The suitable index choice considers two fundamental criteria:

[19] The drop in resource receipts in 2008–09 can be attributed almost entirely to the deleterious effects of the global financial crisis.

[20] An optimal centrality measure for a given application may be suboptimal for another application. This helps explain the existence of many centrality measures in the literature. The function *pca_centralities* allows the indices to be classified according to their respective contributions. The technique is based on a principal component analysis (Josse et al. 2011).

(i) the execution cost of the index (i.e. the computational cost); and (ii) the contribution of the index to the formation of the information contained in the network. Van Der Maaten (2014) introduced the first criterion, which typically involves high-dimensional data. It is an algorithm that returns the computational cost of each index, allowing for a choice between competing indices. A preference is given to indices that are less consuming in computation time.[21] The second criterion is the contribution of the centrality indices to the formation of information. The idea is to retain the most informative indices according to the graph structure considered. In this paper, we mainly consider vertex metrics that can be used to identify unique or important countries within a network, including degree centrality, betweenness centrality, eigenvector centrality, and closeness centrality.

Degree centrality index

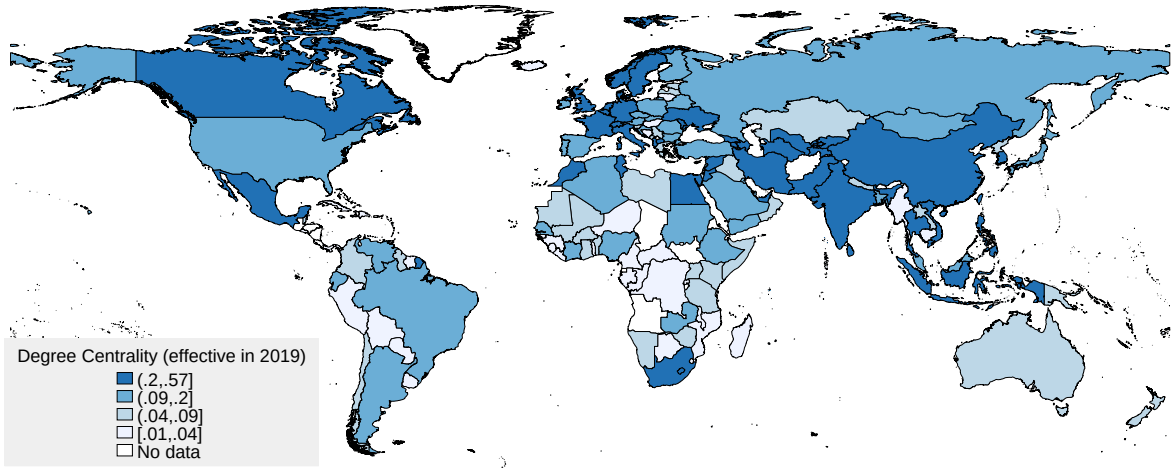
Degree centrality is the most basic and simplest measure of centrality to compute. It is defined as the number of (cardinal) links of a given node (in our case, a given country). The degree centrality index calculates the density of a given country by taking the ratio of the effective links to the potential links of the country (Equation 1).

$$C_i^d = \frac{d_i(\alpha)}{n-1} \in [0,1] \quad (1)$$

where $d_i(\alpha)$ is the number of links of country *i* and *n* is the total number of countries in the network. That is, $d_i(\alpha)$ represents the number of tax treaties a source country has within the total tax treaty network in the sample of countries. While the index considers the number of links for each country, a key limitation of this index is that it does not integrate the location of a country in the network (i.e. it does not demonstrate how important a country is in the overall network, which in our study, comprises 181 countries). Figure 4 shows a map of the world's countries according to the degree centrality index of their bilateral taxation treaties in 2019. Degree centrality is our main independent variable of interest, and in its specific case it is simpler to find the whole number of signed treaties by multiplying the centrality index by *n-1=180*. This facilitates interpretation and allows us to explore the impact of DTTs more effectively.

[21] Using the *tsne_centralities* function, we manage to rank our centrality indices according to their execution cost. Closeness and eigenvector centrality indices are the most time-consuming. Betweenness and degree centrality indices have a shorter computation time. However, this criterion is not crucial in our case, given our sample size or data dimension.

Figure 4: Degree centrality



Source: authors' construction using International Centre for Tax and Development (ICTD) data.

Betweenness centrality index

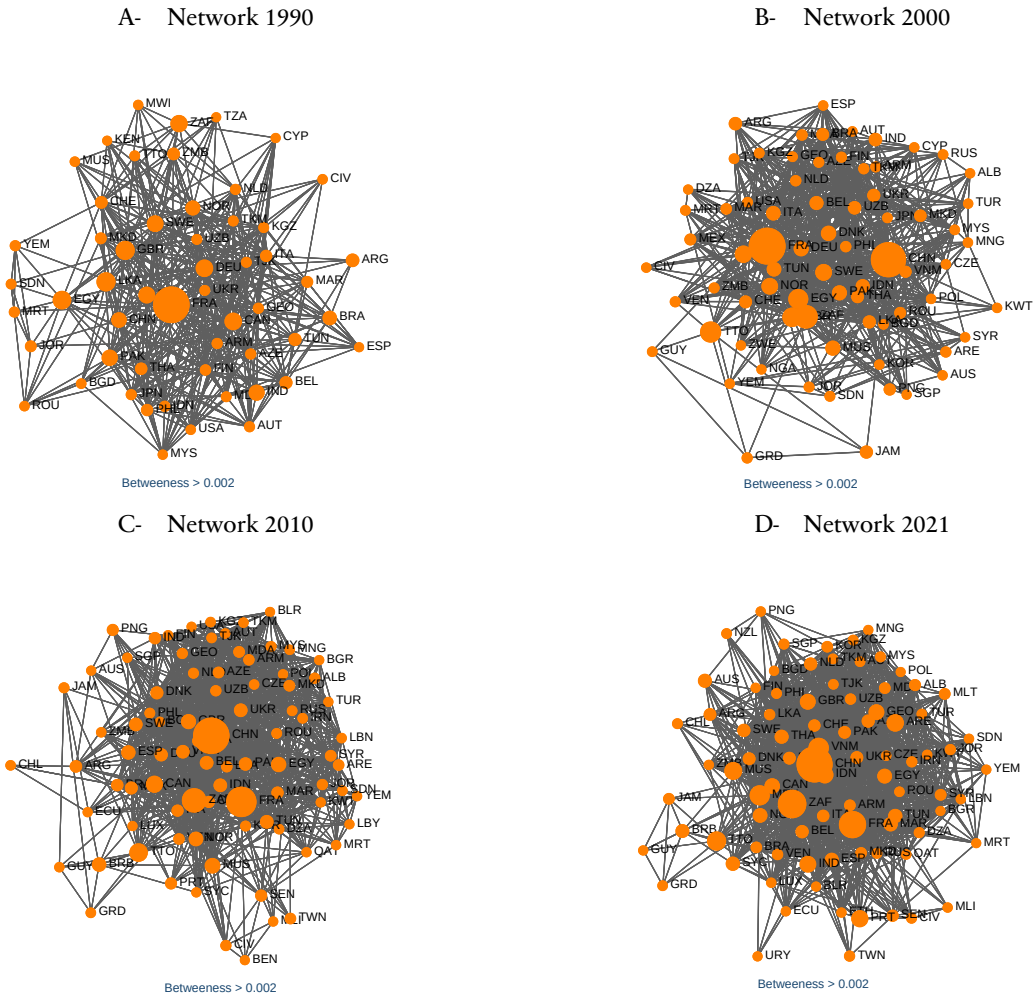
Betweenness centrality is a widely used measure that captures a country's role in allowing information to pass from one part of the network to another (Golbeck 2015). It measures the number of times a given node (country) is the shortest path (i.e. geodesic) between any other couple of nodes (countries) in the network. The most central country in the context of betweenness is the one that appears most often on the shortest path between any two countries, indicating how important a country is for connecting others. In the BTT literature, the shortest path between two jurisdictions will be the intermediate jurisdiction—typically investment, marketing and/or tax hubs—through which investments are routed (Equation 2).

$$C_i^B(\alpha) = \sum_{i \neq j} \frac{P_i(k,j)/P(k,j)}{(n-1)(n-2)/2} \quad (2)$$

where $P_i(k,j)$ is the number of shortest paths between country *i* and country *j* passing through country *i* and $P(k,j)$ is the number of shortest paths between country *k* and country *j*. $\frac{P_i(k,j)}{P(k,j)}$ measures the importance of country *i* to connect country *k* and country *j*. Thus, country *i* will be the shortest distance between countries *k* and *j*, due to country *i* being potentially an investment and/or tax hub.

Betweenness centrality is very important in this study, as it allows us to approximate the countries that form a network of investment or tax hubs (most likely host to shell companies) through which investments can be routed, perpetuating treaty shopping, which exacerbates revenue losses from tax treaties. Figure 5 shows the evolution of the betweenness centrality index over four sample periods. At first glance, it is possible to identify the most central countries in terms of their betweenness in the network. According to the treaty network, some countries that were not betweenness countries in 1990 are betweenness countries in 2000, 2010, or 2021. Other countries remain unchanged irrespective of the termination or suspension of treaties. These countries would attract fewer shell companies (Figure A1 in Appendix A shows a map of the world's countries according to the betweenness centrality index of their tax treaties network in 2019.)

Figure 5: Network analysis—evolution of betweenness centrality from 1990 to 2021



Note: the figure shows an undirected network. The year represents the year of effectiveness of the treaties. Node sizes are represented by the betweenness centrality index (not standardized). The graph has been simplified by allowing only countries with a certain threshold of betweenness (as mentioned below each chart) for clarity.

Source: authors' construction using ICTD data.

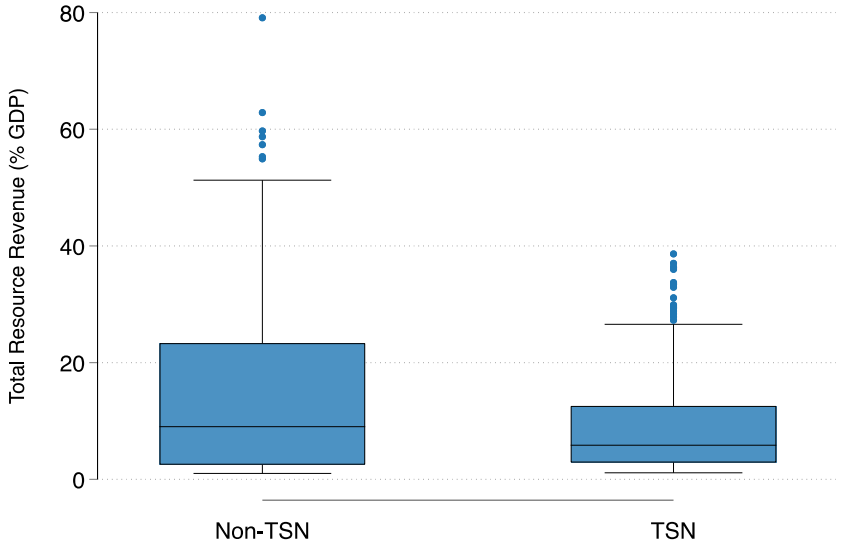
To assess the impact of treaty shopping networks on resource revenue mobilization, we use different quartiles (i.e. Me and Q3) to identify betweenness countries (investment and/or tax hubs).[22] Betweenness countries are those above the threshold of the median (Me) of the betweenness centrality index. This allows us to distinguish baseline countries in two groups: countries that have signed a DTT with at least one betweenness country (hereafter TSN) and countries that have not signed a DTT with a betweenness country (hereafter non-TSN).[23] Figure

[22] The advantage of our procedure is that quartiles are calculated annually but not simultaneously for all countries. This means that each country is considered a 'betweenness' country only in years when it is classified in the 'betweenness' category, according to the level of betweenness index relative to the quartile. For example, a country may not be classified as a 'betweenness' country at the beginning of the sample period but may subsequently become one because of changes in its centrality index relative to the other countries in the network.

[23] In this paper, TSN is used to designate countries that at a given date have signed at least one tax treaty with a betweenness country (i.e. an intermediate jurisdiction). These countries are *de jure* connected to large treaty networks that could facilitate and encourage treaty shopping. We do, however, have a database of TSN and non-TSN countries (see the list of countries in Appendix A).

6 shows a bivariate plot of total resource revenue (% GDP) over the sample period, distinguishing between TSN and non-TSN countries. The plot shows strong heterogeneity between the two sets of countries. Median resource revenue is lower for countries that have signed at least one tax treaty with an investment and/or tax hub (betweenness country). In addition, there is greater dispersion in resource revenue for non-TSN countries than for TSN countries, with larger outliers in the former.

Figure 6: Distribution of resource revenue by betweenness centrality index



Note: in the box plots, the lower and upper ends of each box indicate the 25th and 75th percentiles of the samples, respectively, and the line in the box indicates the respective medians. The ends of the whiskers mark the next adjacent values.

Source: authors' construction using GRD and ICTD Source Index Dataset.

Closeness centrality index

Closeness centrality measures each country's position in the network in a different perspective from the other network metrics, capturing the average distance between each county (farness) and every other country in the network. Specifically, it is the inverse of the average shortest distance between the country and all other countries (vertices) in the network (Bavelas 1948; Hansen et al. 2011) generated using the formula *1/farness* (average distance to all other countries).[24] Thus, a more central country has a smaller distance to all other countries. This centrality index allows us to state how quickly a country can be reached from other countries (Equation 3).

$$C_i^e(\alpha) = \frac{n-1}{\sum_{i \neq j} l(i,j)} \quad (3)$$

where $l(i,j)$ is the number of links on the shortest path between countries *i* and *j*, and *n* is the number of countries in the network.

[24] The betweenness centrality and closeness centrality indices are inversely related to the rates of withholding tax to be paid by MNEs, implying that the higher the rates established in the tax treaties, the lower the index value of centrality.

Eigenvector centrality index

The eigenvector centrality index of a country increases when its neighbouring countries become more influential (i.e. more central). This centrality index incorporates the characteristics of the neighbours of the considered country. It lets us say whether the neighbouring countries are important, central, or influential. The eigenvector centrality of a country is proportional to the sum of the centrality indices of its neighbours. For instance, if A and B have the same degree centrality but A is tied to all high-degree countries and B is tied to all low-degree countries, we intuitively expect to see A with a higher eigenvector centrality score than B (Equation 4).

$$C_i^e(\alpha) = \frac{\sum_{j=1}^{n} v_{ij} C_i^e(\alpha)}{\lambda} \tag{4}$$

where $C_i^e(\alpha)$ is the eigenvector centrality index of the country (node) *i* associated to the network, and $v_{ij} = 1$ if *i* and *j* are connected and 0 otherwise. The prestige of country *i* increases if the prestige of one of its neighbours *j* increases. Bonacich (1972) states that eigenvector centrality allows a better representation of network centrality because, unlike degree centrality, which assigns the same weight to all countries, eigenvector centrality assigns weights to each country according to its position in the network. Eigenvector centrality can also be seen as a weighted sum of all countries' direct and indirect links. Thus, it takes into account the entire model in the network. Furthermore, Bonacich (2007) points out that eigenvector centrality has advantages over graph-theoretic measures like degree, betweenness, and closeness centrality when it comes to also incorporating indirect links, and not only direct links, between different countries.

5 Empirical strategy

To estimate the impact of the degree centrality of BTTs on resource revenue mobilization in source countries, we postulate the following equations:

$$\begin{cases} tax_{it} = \mu_i + \delta_t + \beta_1 BTT_{it} + \beta_2 X_{it} + \varepsilon_{it} \quad (a) \\ tax_{it} = \mu_i + \delta_t + \alpha_1 tax_{it-1} + \beta_1 BTT_{it} + \beta_2 X_{it} + \varepsilon_{it} \quad (b) \end{cases} \tag{5}$$

where tax_{it} represents the measure of resource revenue collection (as a percentage of GDP) in country *i* at time *t*, BTT_{it} represents the degree centrality index of tax treaties, and X_{it} is a vector of control variables. μ_i captures unobservable, time-invariant factors that permit estimation of within-country variations. Since the data are characterized by heterogeneity, unobserved country-specific, time-invariant characteristics—the most important of which is natural resource endowment, hence, discovery—influence both (resource) revenue mobilization and structural and governance variables. The fixed effects (within) estimator deals with this kind of heterogeneity. δ_t represents time-varying factors that affect both resource revenue mobilization and tax treaties and control variables. ε_{it} is the error term with standard properties. We assume that the vector of parameter coefficients, β_1, β_2, is the same across countries (slope homogeneity) and constant over time. Due to dynamics and persistence in the tax revenue variables, a dynamic model (a one-period lag) is introduced.

Reverse causality and other forms of endogeneity may plague the relationship between centrality indices and resource revenue mobilization. For example, having many treaties within the total treaty network may be deliberate treaty policy in a specific source country. Source countries can sign treaties with other countries, especially investment and tax hubs, where FDI and tax revenue are high and expected to grow, and vice versa (Beer and Loeprick 2021). This gains more

importance for resource-rich countries that rely heavily on MNEs and international expertise to extract and process their natural resources, and that are susceptible to profit shifting through the tax hubs. In a bid to attract investment (hence, expand the tax base and increase revenues) resource-rich source countries may be inclined to sign treaties with residence countries and investment hubs. The relationship between resource revenue mobilization and centrality indices may be simultaneous: increased/reduced revenues necessitating the signing of more treaties, which themselves increase or reduce revenues. In addition, structural characteristics in a country may drive the political economy factors that are the primary determinants of tax treaties (including tax treaties with investment hubs), as well as determining the amount of (resource) revenue countries can collect.

Including the lagged dependent variable biases the standard ordinary least squares (OLS) and fixed effects estimators, since the lagged dependent variable is correlated with the error term, a bias exacerbated in short panels (Nickell 1981). The GMM model is suitable for dealing with this kind of bias, as well as potential endogeneity of independent variables. The approach instruments the independent variables with lagged levels and lagged differences and has the advantage of addressing both the problem of endogeneity and unobserved heterogeneity. The system GMM estimator combines the equation in first differences with the equation in levels and uses lagged first differences of independent variables as instruments for the equation in levels, and lagged levels of independent variables as instruments for the equation in first differences. The main assumption in the method is that, conditional on the control variables, lagged independent variables do not react to current changes in resource revenue mobilization.

The validity of the system GMM is ascertained using two diagnostic tests (Blundell and Bond 1998): first, the *p*-value of the Hansen *J* test of over-identifying restrictions, i.e. a test of the orthogonality of the instruments to the error term (the test for instrument validity). This test confirms the relevance of lagged centrality indices as instruments. Second, the Arellano-Bond tests of first- and second-order serial correlation in the residuals, as well as the number of instruments used in each regression (Arellano and Bond 1991). For an appropriate empirical model, the *p*-value on the first-order serial correlation test must be significant, the *p*-value on the second-order test must be insignificant, and the number of instruments must be less than the number of cross-sections (Roodman 2009).

6 Results

6.1 Baseline results

The baseline empirical findings apply the standard panel fixed effects model (within estimator) with resource revenue as dependent variable (for a sample of countries with a resource rents-to-GDP ratio greater than 5 per cent). Results are reported in Table 1, first for all control variables without measures of institutions (column [1]), then progressively including each measure of institutions (columns [2]–[6]).

The results show that the degree centrality of a BTT reduces resource revenue in resource-rich countries. A one unit increase in the degree centrality of the BTT can induce a decrease of up to 0.11 percentage points in resource revenue in source countries. The more BTTs a source country has, within the total available BTT network, the more its resource revenue mobilization is eroded. We argue that this is the case because these countries have lower statutory withholding tax rates (and low withholding tax rate differentials due to treaty-induced rates) and probably depend less on corporate income tax, hence their willingness to forgo some resource revenue. In addition,

because these countries impose low rates on passive and active income, they can be more attractive to different kinds of FDI.

Table 1: Baseline results—FE

Dependent variable: resource revenue (% GDP)	**[1]**	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**
Degree centrality	-0.085***	-0.088***	-0.065**	-0.082***	-0.105***	-0.081***
	(0.025)	(0.028)	(0.028)	(0.029)	(0.028)	(0.027)
Log GDP per capita	1.592***	1.746***	2.068***	1.821***	1.726***	1.544***
	(0.273)	(0.313)	(0.304)	(0.312)	(0.308)	(0.292)
Resource rents (% GDP)	0.319***	0.403***	0.403***	0.401***	0.393***	0.327***
	(0.022)	(0.028)	(0.027)	(0.028)	(0.028)	(0.022)
Inflation (CPI %)	-0.039**	-0.036*	-0.013	-0.037*	-0.031	-0.046**
	(0.018)	(0.021)	(0.021)	(0.021)	(0.021)	(0.019)
Trade (% GDP)	0.009	-0.001	-0.011	-0.004	-0.000	0.009
	(0.008)	(0.010)	(0.010)	(0.010)	(0.010)	(0.008)
FDI (% GDP)	-0.133***	-0.144***	-0.138***	-0.137***	-0.149***	-0.139***
	(0.022)	(0.026)	(0.025)	(0.026)	(0.026)	(0.022)
Democratic risk		0.555***				
		(0.203)				
External conflict risk			1.509***			
			(0.173)			
Investment profile risk				0.255*		
				(0.130)		
Socioeconomic conditions risk					0.646***	
					(0.146)	
Control of corruption						0.810
						(0.542)
R-squared	0.314	0.314	0.314	0.314	0.314	0.314
Observations	754	578	578	578	578	719
Countries	49	42	42	42	42	49

Note: results are for the sample of countries with a resource rents-to-GDP ratio greater than 5%. GDP = gross domestic product; FDI = foreign direct investment; CPI = consumer price index; FE = fixed effects. ***, **, and * denote statistical significance at 1, 5 and 10% levels, respectively. Standard errors are reported in parentheses.

Source: authors' construction.

The signs of control variables match their a priori expectations. Resource rents and per capita GDP have strong positive impacts on resource revenues, while inflation has a negative impact in most models. Trade openness is insignificant in all the models, indicating its lack of importance in influencing resource revenues (since the variable does not exclusively measure resource exports and imports, its impact may be entirely on total government revenue). The institutional variables are also positive and significant, excluding the control of corruption index. The FDI-to-GDP ratio is negative and significant across all models, and the negative FDI effect may be driven by the prevalence of tax incentives in the extractives sector (ECA 2019; Readhead 2018), the prevalence of MNEs crowding out less competitive domestic local companies (Camara 2023), and the accumulation of different kinds of FDI with no revenue effects (e.g. phantom FDI and mergers and acquisitions). [25]

[25] Damgaard et al. (2019) describe phantom investments as those that pass through corporate shells (special-purpose entities) with no real business activities. They are typically set up to conduct intrafirm financing or manage intangible assets.

Table 2 reports the findings from applying the system GMM, reported analogously to Table 1.

Table 2: Baseline results—GMM

Dependent variable: resource revenue (% GDP)	**[1]**	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**
Dependent variable (lagged)	0.570*** (0.088)	0.345*** (0.055)	0.642*** (0.033)	0.522*** (0.013)	0.393*** (0.053)	0.682*** (0.025)
Degree centrality	-0.073** (0.036)	-0.097** (0.049)	-0.024** (0.012)	-0.033*** (0.009)	-0.113** (0.054)	-0.021** (0.010)
Log GDP per capita	2.978*** (1.339)	3.231*** (1.067)	0.664*** (0.243)	0.734*** (0.188)	2.086*** (0.760)	0.470*** (0.191)
Resource rents (% GDP)	0.179*** (0.059)	0.378*** (0.075)	0.183*** (0.020)	0.291*** (0.014)	0.407*** (0.055)	0.099*** (0.025)
Inflation (CPI %)	0.015 (0.030)	-0.098* (0.054)	-0.015 (0.010)	-0.026** (0.011)	-0.094** (0.045)	-0.006 (0.012)
Trade (% GDP)	-0.022 (0.015)	-0.094 (0.067)	0.023*** (0.009)	0.012 (0.009)	-0.110** (0.051)	0.015** (0.006)
FDI (% GDP)	-0.018 (0.021)	0.035 (0.089)	-0.413*** (0.037)	-0.437*** (0.051)	-0.068 (0.069)	-0.269*** (0.061)
Democratic risk		-0.243 (0.346)				
External conflict risk			0.033 (0.100)			
Investment profile risk				0.258*** (0.082)		
Socioeconomic conditions risk					0.853** (0.403)	
Control of corruption						-0.328 (0.386)
Observations	710	539	539	539	539	675
Countries	49	42	42	42	42	47
Instruments	16	16	24	28	17	21
Chi2 *p*-value	0.000	0.000	0.000	0.000	0.000	0.000
Hansen *J* *p*-value	0.192	0.211	0.585	0.384	0.392	0.622
AR (1) *p*-value	0.039	0.066	0.059	0.057	0.059	0.058
AR (2) *p*-value	0.181	0.261	0.246	0.292	0.323	0.368
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

Note: results are for the sample of countries with a resource rents-to-GDP ratio greater than 5%. GDP = gross domestic product; FDI = foreign direct investment; CPI = consumer price index; FE = fixed effects. ***, **, and * denote statistical significance at 1, 5, and 10% levels, respectively. Standard errors are reported in parentheses. In all specifications, the null hypothesis for the lack of first-order (AR (1)) serial correlation in the first-differenced error terms is rejected, while the null hypothesis for the lack of second-order (AR (2)) serial correlation cannot be rejected. The number of instruments is limited to avoid over-fitting the model (as expected, the number of instruments is less than the number of countries). In addition, the *p*-value on the Hansen *J* test for overidentifying restrictions fails to reject the null hypothesis that the model is correctly specified, and the instrument set is valid.

Source: authors' construction.

The diagnostic tests validate the dynamic specification. The coefficient on the lagged dependent variable is consistently positive and significant at the 1 per cent level, confirming inertia in resource revenue mobilization. The *p*-value on the Hansen *J* test is insignificant (i.e. greater than 10 per cent), indicating that the model is correctly specified, and the instrument set is valid. In addition, the total number of instruments is lower than the number of countries. Furthermore, the *p*-value on the first-order serial correlation test is zero and significant, while the p-value on the second-order serial correlation is non-zero and insignificant. Taken together, these diagnostics confirm the adequacy of applying the system GMM estimator. The results are largely robust. A one-unit

increase in the degree centrality index reduces resource revenue mobilization by between 0.021 and 0.11 percentage points. All control variables show similar signs and strength of significance (when significant) and, as expected, the GMM coefficients are smaller.[26]

6.2 Robustness analysis

Alternative measures of centrality

We use alternative measures of the centrality index, specifically betweenness, eigenvectors, and closeness centrality indices. Each centrality index is introduced independently, with results reported in Table 3.

Table 3: Alternative measures of centrality

Dependent variable: resource revenue (% GDP)	**[1]**	**[2]**	**[3]**	**[4]**
Betweenness centrality	10.467			
	(9.089)			
Degree centrality		-15.274***		
		(4.547)		
Closeness centrality			-27.940***	
			(6.766)	
Eigenvector centrality				-44.543***
				(11.034)
Log GDP per capita	1.034***	1.592***	1.797***	1.268***
	(0.214)	(0.273)	(0.284)	(0.220)
Resource rents (% GDP)	0.334***	0.319***	0.312***	0.324***
	(0.022)	(0.022)	(0.022)	(0.022)
Inflation (CPI % annual)	-0.045**	-0.039**	-0.048***	-0.038**
	(0.018)	(0.018)	(0.018)	(0.018)
Trade (% GDP)	0.003	0.009	0.009	0.006
	(0.007)	(0.008)	(0.007)	(0.007)
FDI (% GDP)	-0.123***	-0.133***	-0.123***	-0.128***
	(0.022)	(0.022)	(0.022)	(0.022)
R-squared	0.304	0.314	0.319	0.319
Observations	754	754	754	754
Countries	49	49	49	49

Note: as for Table 1.

Source: authors' construction.

The coefficients on the centrality indices are also negative and significant at 1 per cent in three of the four specifications.[27] The degree centrality index is now normalized by the number of countries in the network, making its coefficient (column [2]) greater here than the estimates in Table 1. We

[26] Analogous estimates for a sample of countries with resource rents-to-GDP ratios greater than 10 per cent are presented in Tables B1 and B2 in Appendix B.

[27] These indicators analysing connections between countries via tax treaties are difficult to interpret, given that (weighted) rates are incorporated into the analysis, with the resulting values a combination of two contradictory effects. First, the values are higher when 'neighbours' have more tax treaties. Second, the values are higher when treaty-withholding rates are higher. Generated standardized coefficients can be used to interpret standard deviation variation but are not used for panel data because of their ambiguity. Hence, we focus on the sign of the respective centrality indices and do not attempt to contextualize the magnitude.

still see a negative relationship between degree centrality and resource revenue mobilization in source countries.

The coefficient on betweenness centrality (column [1]) is insignificant, which may be explained by its inherent design to capture the indirect impact of intermediary countries. The source countries—resource-rich countries—are not necessarily the intermediate countries, such that the latter would not see a significant variation in their revenues from extractive resources. Column [3] shows a negative and significant relationship between closeness centrality and resource revenues. Closeness centrality measures the inverse of the average shortest distance between a county and all other countries in the network. Thus, a source country with a high closeness centrality index has a smaller distance from all other countries and is theoretically more inclined to attract foreign investment due to greater localization. In other words, a foreign investor would pass through fewer intermediary countries before reaching the specific source country. It should be noted that the greater the number of intermediary countries, the greater the loss of profits to be transferred from a source country to a country of residence.

Eigenvector centrality measures the importance of a country by considering the importance of its neighbours (its links). For example, a country with 10 less attractive partners in the treaty network will have a lower eigenvector centrality index than a country with 10 very attractive partners (such as Mauritius). The basic principle is that links from important countries (measured by eigenvector centrality) are more valuable than links from relatively unimportant countries (in the eyes of foreign investors wishing to optimize their tax position). For example, a source country with Mauritius (classified as a tax hub) as a treaty partner will have a higher eigenvector centrality than one with Tunisia as a treaty partner. Column [4] shows a negative and significant association between the eigenvector centrality index and government resource revenue. Source countries with higher eigenvector centralities would attract more foreign investment because of their connection with the most influential partners (which may be investment hubs).

Alternative measures of revenue mobilization

Table 4 presents the fixed effects estimates with total domestic revenue as dependent variable, reported analogously to Table 1.[28] The findings largely match those in Table 1. The degree centrality index and total domestic revenue have a negative and significant relationship, which is robust across specifications. A one-unit increase in the centrality index results in a maximum 0.09 percentage point reduction in total domestic revenue. The mechanisms through which tax treaties erode resource revenue mobilization still apply here, given that tax treaties are not necessarily sector-specific. In addition, resource-rich countries have fiscal regimes skewed towards the extractives sector, which dominates receipts (extractives receipts also dominate non-tax revenues), such that the negative effects of tax treaties on resource revenues may dominate any other effects. The control variables are also robust, with per capita GDP, resource rents, and (occasionally) inflation all being significant (matching the literature). Trade openness is now positive and robust across models, suggesting that increased trade (both imports and exports) generates significant increases in domestic consumption and corporate profits, which can be taxed. The FDI ratio is still negative and significant, albeit lower than in the baseline findings.

[28] Total government revenue is the sum of tax and non-tax revenue, the latter distinguishing between resource (e.g. royalties from mining operations) and non-resource components (e.g., fines, charges, and fees).

Table 4: BTTs and total domestic revenue

Dependent variable: resource revenue (% GDP)	**[1]**	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**
Degree centrality	-0.094***	-0.070**	-0.056	-0.060*	-0.082**	-0.093***
	(0.033)	(0.034)	(0.034)	(0.034)	(0.034)	(0.034)
Log GDP per capita	2.696***	2.312***	2.438***	2.321***	2.195***	2.534***
	(0.341)	(0.359)	(0.363)	(0.360)	(0.359)	(0.365)
Resource rents (% GDP)	0.225***	0.284***	0.285***	0.283***	0.279***	0.225***
	(0.027)	(0.030)	(0.030)	(0.030)	(0.030)	(0.027)
Inflation (CPI %)	-0.024**	-0.012	-0.004	-0.008	-0.003	-0.025**
	(0.012)	(0.020)	(0.020)	(0.020)	(0.020)	(0.012)
Trade (% GDP)	0.028***	0.028***	0.024**	0.026**	0.029**	0.025**
	(0.009)	(0.012)	(0.012)	(0.012)	(0.012)	(0.010)
FDI (% GDP)	-0.017	-0.049*	-0.044*	-0.044*	-0.052**	-0.022
	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)	(0.025)
Democratic risk		0.605***				
		(0.217)				
External conflict risk			0.380*			
			(0.198)			
Investment profile risk				0.253*		
				(0.140)		
Socioeconomic conditions risk					0.628***	
					(0.170)	
Control of corruption						-0.161
						(0.691)
R-squared	0.165	0.223	0.218	0.218	0.230	0.149
Observations	1031	728	728	728	728	988
Countries	66	50	50	50	50	66

Note: as for Table 1.

Source: authors' construction.

Table 5 is analogous to Table 4, with non-resource government revenue as dependent variable. The results are considerably less robust, with a significant relationship apparent in only two of the six models. Regarding all the specifications, the relationship between degree centrality and non-resource government revenue seems mitigated. This tacitly corroborates our arguments above that, for resource-rich countries, the negative effects of tax treaties on resource components overshadow most other possible effects. GDP per capita has a strong positive association with tax revenue, while resource rents are negatively associated with tax revenue (see Bornhorst et al. 2009; Crivelli and Gupta 2014).[29] Inflation loses its significance, while trade openness consistently has a strong positive relationship with tax revenue through increased domestic consumption and corporate profits. The FDI ratio is now positive and robustly significant, suggesting that for non-resource government revenue, the positive effects of FDI outweigh any potential negative effects that occur through the adverse effects of MNE tax incentives and non-productive foreign investment. The positive effects of FDI could be either direct (through job creation and increased productivity—hence, more PIT and CIT) or indirect (through increased consumption and trade—hence, more customs duties and value-added tax). Institutional variables are insignificant.

[29] A negative effect of resource rents on non-resource tax revenue is more often espoused in the literature, most studies positing that alternative sources of income (in the form of foreign aid and natural resource revenue) obviate the need to invest in developing the necessary fiscal capacity to administer and collect taxes (see Morrissey 2015 for a discussion).

Table 5: BTTs and total non-resource revenue

Dependent variable: resource revenue (% GDP)	**[1]**	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**
Degree centrality	-0.048**	0.007	0.006	-0.002	0.003	-0.046*
	(0.023)	(0.022)	(0.022)	(0.022)	(0.022)	(0.025)
Log GDP per capita	1.678***	1.226***	1.226***	1.292***	1.243***	1.600***
	(0.229)	(0.214)	(0.214)	(0.213)	(0.213)	(0.249)
Resource rents (% GDP)	-0.094***	-0.088***	-0.088***	-0.084***	-0.090***	-0.099***
	(0.018)	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)
Inflation (CPI %)	0.003	-0.001	-0.001	-0.000	-0.001	0.004
	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.016)
Trade (% GDP)	0.016**	0.037***	0.036***	0.035***	0.036***	0.016**
	(0.006)	(0.007)	(0.007)	(0.007)	(0.007)	(0.006)
FDI (% GDP)	0.074***	0.077***	0.080***	0.081***	0.078***	0.074***
	(0.018)	(0.018)	(0.018)	(0.017)	(0.018)	(0.019)
Democratic risk		0.206				
		(0.139)				
External conflict risk			0.012			
			(0.124)			
Investment profile risk				-0.153*		
				(0.088)		
Socioeconomic conditions risk					0.105	
					(0.100)	
Control of corruption						-0.251
						(0.4659
R-squared	0.136	0.200	0.196	0.201	0.198	0.125
Observations	740	562	562	562	562	707
Countries	49	41	41	41	41	49

Note: as for Table 1.

Source: authors' construction.

Further regressions estimating the impact of degree centrality on disaggregated non-resource tax revenue aggregates are reported in Table B3. The impact of degree centrality on indirect taxes is insignificant, while the impact on direct taxes, CIT, PIT, and goods and services taxes is positive and significant. The number of BTTs within the total treaty network, while deleterious to total resource and non-resource revenue, increases direct taxes (and their components) and goods and services taxes. The positive effects on direct taxes (and their constituent parts) can be expected insofar as the existence of tax agreements can be associated with more non-resource foreign investment and non-resource trade, potentially resulting in increased PIT (especially payroll taxes from expatriates) and CIT, as well as higher domestic consumption (hence, more goods and services taxes). The degree centrality index has a negative relationship with taxes on international trade, a one-unit increase in the index resulting in a 0.019 percentage point reduction in trade taxes. This negative effect on taxes on international trade can be explained by the overly generous tax exemptions granted by resource-rich source countries under domestic law and exploited by tax treaties, e.g., exemptions on import VAT and excises, import duty waivers, and customs duty waivers.[30]

[30] The negative effect of tax treaties on trade taxes may be exacerbated by the availability, or lack thereof, of VAT refunds. MNEs that export their minerals are entitled to VAT refunds for taxes paid on importing their inputs. For liquidity-constrained resource-rich countries, the inability of governments to provide VAT refunds is countered by MNEs demanding more VAT exemptions.

7 Treatment effects of signing BTTs with investment and/or tax hubs

We are interested in gauging the resource revenue impact of signing a tax treaty with an investment or tax hub, arguing that countries that sign treaties with investment hubs perpetuate treaty shopping, which exacerbates revenue losses from tax treaties. As argued in Section 2, we use the betweenness centrality index to split countries, at the median (Me) and at the third quartile (Q3), between high and low centrality. Those above the threshold (Me or Q3) are investment and/or tax hubs—with which resource-rich source countries sign tax treaties (hence, perpetuating treaty shopping)—that are in the group of TSN (treated), otherwise in the group of non-TSN (untreated). We do some basic exploratory analysis—*t*-tests for differences in means—to describe resource revenue mobilization and fiscal regimes across both sets of countries. Results are shown in Table 6.

Table 6: Overview of fiscal regimes for TSN and non-TSN countries

Variable	Time	Non-TSN	TSN	Difference	*t*-test	*p*-value
Resource revenue (% GDP)	Entire period	6.155	5.205	0.950	1.485	0.138
Resource revenue (% GDP)	Last 15 years	6.768	5.102	1.666	2.131	0.033**
Resource revenue (% GDP)	Last 10 years	6.459	4.432	2.026	2.287	0.023**
Resource revenue (% GDP)	Last 5 years	5.388	3.035	2.352	2.421	0.016**
CIT rate (%)	Entire period	28.854	27.985	0.869	2.438	0.015**
Revenue forgone (% GDP)	Entire period	1.225	1.601	-0.376	-1.794	0.074*
WH-Rate (dividends)	Entire period	11.020	6.735	4.288	8.741	0.000***
WH-Rate (interest)	Entire period	12.651	6.702	5.949	8.861	0.000***
WH-Rate (royalties)	Entire period	14.835	9.202	5.633	8.989	0.000***

Note: WH-Rate = withholding tax rate; CIT = corporate income tax; GDP = gross domestic product. TSN refers to countries that have signed tax treaties with investment hubs (classified as those with a betweenness centrality index above the median). Non-TSN refers to countries that have not signed tax treaties with investment hubs. ***, **, and * denote statistical significance at 1, 5 and 10% levels, respectively.

Source: authors' construction.

The table shows that there are differences in resource revenue mobilization (and revenue mobilization, in general) across both sets of countries at different periods. Over the entire sample period, the difference in resource revenue is insignificant. However, moving progressively towards the sample end date, we see that countries with high betweenness centrality indices have lower resource revenues than those with low centrality indices, and the differences are significant (the difference is largest in the last five years). This can be explained by MNEs exploiting gaps between different countries' tax systems, thereby perpetuating base erosion across countries. We also analyse preferential fiscal regimes (proxied by the amount of revenue forgone from businesses or corporate tax incentives, as a percentage of GDP in 2019) and find that revenue forgone is higher in countries that have signed tax treaties with investment hubs.[31] Finally, statutory CIT and withholding tax rates on dividends, interest, and royalties show significant differences between non-TSN and TSN countries. There is a significant reduction in taxation rights on passive income in TSN countries.

[31] Data on revenue forgone from tax incentives (both in nominal values and as a percentage of GDP) are obtained from the Global Tax Expenditures Database (GTED) 2023.

Entropy balancing

We employ the entropy balancing method to estimate the impact of signing a tax treaty with an investment hub on resource revenue mobilization in source countries. The method is based on the idea that signing a tax treaty with an investment hub (and potentially facilitating treaty shopping across countries) may be non-random, thus representing treatment. Those who do not sign treaties with investment hubs constitute a potential control group. While the system GMM counters endogeneity with lags of independent variables, there might still be other forms of endogeneity. First, both the number of treaties in a country and the number of treaties signed with investment hubs may be non-random. Political factors may also determine the signing of multiple tax treaties in a country (Pickering 2013). In addition, signing BTTs with investment hubs may be a deliberate policy by a country, in a bid to route cross-border investments, situate mobile entities in mining value chains, and accrue other associated benefits from being part of a tax treaty network with investment hubs. Second, confounding factors drive the number of treaties countries sign, the decision to sign treaties with investment hubs, and the amount of (resource) revenues they can raise.

Our analysis is based on the idea that tax treaties with investment and/or tax hubs represent treatment, and the unit of analysis is country–year observations. Observations with TSN in place comprise the treatment group, and observations without TSN constitute a potential control group. The average treatment effect on the treated (*ATT*), is thus defined as:

$$ATT = E[(Y^1 - Y^0)|TSN = 1] = E[Y^1|TSN = 1] - E[Y^0|TSN = 1] \quad (6)$$

where *Y* is the outcome variable, measuring resource revenue mobilization (percentage of GDP) and *TSN* indicates whether a unit is exposed to treatment (*TSN=1*) or not (*TSN=0*). Thus, $E[Y^1|TSN = 1]$ is the expected outcome for the treatment group after signing a tax treaty with an investment hub, and $E[Y^0|TSN = 1]$ is the outcome for the treatment group if it had not signed a tax treaty with at least one investment hub (betweenness country) from a given year. Due to the non-random nature of signing a tax treaty with an investment hub, the counterfactual $E[Y^0|TSN = 1]$ is unobservable, thus requiring a good proxy. If it were observable, the *ATT* could easily be identified by comparing revenue mobilization in *TSN* countries with that in non-*TSN* countries.

To generate an adequate proxy, we match *TSN* units with non-*TSN* units that are as close as possible to observable characteristics, based on two criteria: first, characteristics that are associated with selection into treatment (i.e. deciding whether to sign a tax treaty with an investment hub); second, characteristics that influence the outcome of interest (i.e. variables typically included in the tax performance literature). Under the condition that the non-*TSN* units are close to the *TSN* units, any difference in revenue collection is attributable to *DTT*. Based on these different elements, we can rewrite Equation (6) as follows:

$$ATT = E[Y^1 TSN = 1, X = x] - E[Y^0|DTT = 1, X = x] \quad (7)$$

where *X* is a vector of observable covariates that may affect both the decision to sign treaties with an investment hub and revenue mobilization (see discussion in Section 4), $E[Y^1|TSN = 1, X = x]$ is the revenue collection of *TSN* units (the treatment group), and $E[Y^0|TSN = 1, X = x]$ is the expected revenue collection of the synthetic control units.

Estimating the *ATT* by entropy balancing consists of two main steps. The first step is to compute weights for the control group. These weights may satisfy pre-specified balanced constraints

involving sample moments of observable characteristics (X). Following Neuenkirch and Neumeier (2016), we choose balance constraints that impose equal covariate means between the treated and control groups. This ensures that the control group, on average, has non-treatment units that are as similar as possible to the treated units.[32] The second step uses the weights from the first step in a regression analysis where resource revenue is the dependent variable, and the covariates employed in the first step are included as control variables. This is equivalent to including control variables in a randomized experiment and it increases the efficiency of estimation.

In addition, time-specific effects and country-specific effects can be incorporated into the analysis. Including time-specific fixed effects is important for modelling global shocks—such as the global financial crisis, the determination of resource prices on the global markets, and the coronavirus pandemic—that affect countries' resource revenue mobilization and treaty signing. Including country-specific effects permits modelling of time-invariant and unobservable country-specific factors that could result in differences in resource revenue mobilization, as well as differences in tax regimes.

Entropy balancing, which combines matching and regression analyses (Neuenkirch and Neumeier 2016), has three key advantages over other matching methods. First, it ensures a high degree of covariate balance between treatment and control groups, even in small sample sizes.[33] Second, it uses more flexible weighting schemes than conventional matching, in which control units are either eliminated or matched. It reweights units with the aim of achieving a balance between processed and unprocessed units, while keeping the weights as close to the base weights as possible to avoid information loss. Third, the method is non-parametric, hence mitigating concerns of misspecification of the model's functional form (which could bias results) and eliminating multicollinearity (the reweighting mechanism makes the treatment variable orthogonal to the covariates).

As a precursor to the econometric analysis, we present some descriptive statistics on the observable covariates used to compute the treatment effects, before and after weighting. Selecting an adequate control group is crucial before estimating the treatment effect using a matching approach; otherwise, the estimated treatment effects will be biased. While our primary analysis will present results for which the betweenness centrality index is split at the median and third quartile, we also present descriptive statistics for the betweenness centrality index split at the first quartile. Panel A of Table 7 shows descriptive statistics before weighting, while Panel B shows descriptive statistics after weighting. Column [1] presents the sample means for the treated group and column [2] is analogous for the control group, while column [3] reports the difference in means between the two groups. The columns are analogous for the other betweenness thresholds.

[32] This procedure ensures that, once the weights are generated, TSN and non-TSN countries exhibit similar trends in their outcome variable over the period of pre-treatment (Ogrokhina and Rodriguez 2019).

[33] For example, in propensity score matching methods, the control group comprises only a subset of the units not subject to treatment (Diamond and Sekhon 2013; Hainmueller 2012; Neuenkirch and Neumeier 2016). Each untreated unit receives a weight equal to zero if it does not represent the best match for a treated unit or one if it represents the best match for one treated unit (Neuenkirch and Neumeier 2016). However, when the number of untreated units is small and the number of pre-treatment characteristics is large, this procedure does not guarantee a sufficient balance of pre-treatment characteristics between the two groups.

Table 7: Descriptive statistics, before and after weighting

	BEFORE WEIGHTING								
	Threshold>Q1(=25%)			Threshold>Q2(median)			Threshold>Q3(=75%)		
Panel A	**TSN [1]**	**Non-TSN [2]**	**Difference [3] = [1]-[2]**	**TSN [1]**	**Non-TSN [2]**	**Difference [3] = [1]-[2]**	**TSN [1]**	**Non-TSN [2]**	**Difference [3] = [1]-[2]**
Degree centrality index (units)	28.35	7.27	21.08	28.35	7.27	21.08	29.36	7.67	21.69
Log GDP per capita	7.73	7.20	0.53	7.73	7.20	0.53	7.78	7.17	0.62
Resource rents (% GDP)	10.47	9.37	1.10	10.47	9.37	1.10	10.55	9.34	1.21
Inflation (CPI % annual)	0.76	0.55	0.21	0.76	0.55	0.21	0.76	0.57	0.19
Trade (% GDP)	78.18	66.46	11.72	78.18	66.46	11.72	79.61	65.31	14.30
Industrial value added (% GDP)	32.25	24.13	8.12	32.25	24.13	8.12	32.79	24.04	8.75
Fuels and metals exports (% exports)	35.69	33.03	2.66	35.69	33.03	2.66	36.73	31.63	5.1
Observations	691	371		691	371		652	410	
	AFTER WEIGHTING								
	Threshold>Q1(=25%)			Threshold>Q2(median)			Threshold>Q3(=75%)		
Panel B	**TSN [1]**	**Non-TSN [2]**	**Difference [3] = [1]-[2]**	**TSN [1]**	**Non-TSN [2]**	**Difference [3] = [1]-[2]**	**TSN [1]**	**Non-TSN [2]**	**Difference [3] = [1]-[2]**
Degree centrality index (units)	28.35	28.32	0.03	28.35	28.32	0.03	29.36	29.36	0.00
Log GDP per capita	7.73	7.73	0.00	7.73	7.73	0.00	7.78	7.78	0.00
Resource rents (% GDP)	10.47	10.47	0.00	10.47	10.47	0.00	10.55	10.55	0.00
Inflation (CPI % annual)	0.76	0.76	0.00	0.76	0.76	0.00	0.76	0.76	0.00
Trade (% GDP)	78.18	78.16	0.02	78.18	78.16	0.02	79.61	79.60	0.01
Industrial value added (% GDP)	32.25	32.24	0.01	32.25	32.24	0.01	32.79	32.79	0.00
Fuels and metals exports (% exports)	35.69	35.67	0.02	35.69	35.67	0.02	36.73	36.73	0.00
Observations	691	691		691	691		652	652	

Note: this table presents the pre- and post-weighting sample means of the matching covariates for country–year observations where treaties with an investment hub were in place (the treatment group) in column [1] and in the control group in column [2]. Column [3] reports the differences in means between the treated and control groups. We see that the betweenness threshold above the first quartile is the same as the threshold above the median. Thus, for brevity, subsequent tables will report only the betweenness threshold above the median and above the third quartile.

Source: authors' construction.

Panel A of Table 7 shows that there are indeed significant differences between the two groups of countries. Countries in the treatment group are characterized by a higher degree centrality index, higher per capita GDP, less resource rents, lower inflation, higher trade openness, higher industrial value-added, and higher fuel and metal exports. These differences are significant, demonstrating the importance of selecting an appropriate control group for the analysis. Panel B demonstrates the sample means matching covariates after weighting, obtained by entropy balancing. It shows that all the covariates are perfectly balanced between the two groups as the difference between them disappears, demonstrating the effectiveness of the entropy balancing method. The method permits accurate construction of a control group that is very similar to the treatment group.

7.1 Baseline treatment effects

Using the synthetic controls in Table 6, we apply the weighted least squares method to estimate the impact of signing treaties with investment hubs on resource revenue mobilization (ATT). The results are reported in Table 8. Columns [1]–[3] show the estimates using countries that have betweenness centrality above Q1 (investment hubs), and columns [4]–[6] are for betweenness centrality above Q3. In columns [1] and [4] the control of corruption index is excluded (all other columns include the corruption index), while matching covariates from Table 6, country- and year-fixed effects, are included in all second-stage regressions.

Table 8: TSN and resource revenue mobilization

	Threshold>Q2(median)			Threshold>Q3(=75%)		
	[1]	[2]	[3]	[4]	[5]	[6]
TSN (ATT)	-2.053***	-1.535**	-1.882***	-2.887***	-2.136***	-2.631***
	(0.664)	(0.611)	(0.649)	(0.576)	(0.533)	(0.559)
Covariates	Yes	Yes	Yes	Yes	Yes	Yes
Control of corruption	No	Yes	Yes	No	No	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.909	0.927	0.933	0.909	0.926	0.932
Observations	754	578	578	578	578	719

Note: the table presents the effects of signing a tax treaty with an investment hub (the treatment) on resource-rich source countries. Control variables are those included in Table 7. ***, **, and * denote significance at 1, 5, and 10% levels, respectively. Results using treatment based on the first quartiles (i.e. threshold>25%) are the same as those for the median, hence not reported.

Source: authors' construction.

Independent of the empirical specification, signing a tax treaty with an investment hub (thus perpetuating treaty shopping) decreases resource revenue mobilization in source countries. This result is robust, given the relative stability of the coefficients across the specifications in the table. The magnitude of the coefficient varies from 1.5 (column [2]) to 2.9 (column [4]) percentage points depending on the betweenness threshold. In other words, signing a tax treaty with an investment hub decreases resource revenue by around 2.15 percentage points of GDP on average. Our results are consistent with those of McGauran (2013), who shows that resource-rich countries are vulnerable to revenue losses from their association with investment hubs, those losses being exacerbated by treaty shopping. Mongolia—a country that depends on the mining sector for 80 per cent of its exports, 32 per cent of government revenue, and 30 per cent of GDP—cancelled its tax treaties with Luxembourg, Kuwait, the Netherlands, and the United Arab Emirates (UAE)

because those jurisdictions were used to route investments for MNCs with ultimate owners from different countries.[34]

Our findings are also consistent with the two-sided platform theory for tax hubs, whose purpose is to minimize transaction costs (i.e. taxes) between platform users—i.e. source and residence countries—coming together, permitting exchanges that would otherwise not occur (Baistrocchi 2023). The theory shows that in deciding to invest through tax hubs, MNEs ultimately want to minimize their effective tax rates, while source countries want to maximize their inward capital (FDI).[35] MNEs in the extractives sector operate across a wide range of sub-sectors or industries (ranging from mining rights to procurement and sales) that involve significant cross-border transactions, those MNEs occasionally having dedicated entities within the group with a higher ratio of intangible assets. Along the extractives value chain, these entities can be distinguished into mobile and immobile entities. For example, entities involved in acquisition and exploration and mine development are likely to be more immobile, hence subject to higher tax rates. Entities involved in refining and trading (marketing and sales), as well as accounting and legal services, are likely to be more mobile, hence subject to lower effective tax rates.

Tax treaties thus permit more mobile entities to invest via tax hubs, since they will be subject to lower effective tax rates (on both corporate and withholding taxes). This contributes to the resource revenue losses reported in Table 8. This can be exacerbated by the tax deductibility of expenses by mobile entities, i.e. parent companies charging high fees for managerial and technical services, which subsidiaries in source countries deduct from taxable income (thus eroding the tax base in source countries). Even for relatively immobile firms, treaties restricting the ability to tax indirect transfers of assets can incentivize the parent MNEs to structure their transactions to fall outside the source countries' jurisdictions.

7.2 Reverse treatment effect

To ensure that there is no confounding effect, we reversed the direction of treatment. The treatment is now 1 (non-*TSN*=1) for countries that have no tax treaty, with countries assumed to be TSN (investment hubs), and 0 (*TSN*=0) for countries that have signed at least one treaty with countries assumed to be investment hubs. Using the synthetic controls in Table 7, we estimate the effect of non-*TSN* on resource revenue mobilization (ATT). The results are presented in Table 9. Columns [1]–[6] are reported analogously to Table 8. Independent of the empirical specification, not signing a tax treaty with an investment hub increases resource revenue mobilization in source countries compared with signing a tax with an investment hub. The findings are robust, with the ATT significant at 1 per cent in all specifications. The magnitude of the coefficients varies between 2.94 percentage points (column [7]) and 4.14 percentage points (column [1]), with an average effect of 3.52 percentage points of GDP.

[34] The investors benefited from lower withholding tax rates on the major passive incomes (dividends, interest, and royalties), as well as reimbursement for technical services included in the treaties (McGauran 2013).

[35] The two-sided platform theory can easily be extended to our impact evaluation analysis, since tax hubs offer two key network effects: first, cross-side network effects, according to which the better the connectivity of a tax hub with one or more source jurisdictions with which it has a tax treaty, the more incentives MNEs in the extractives sector will have to channel their investments through the tax hub. Second, same-side network effects, by which the more MNEs in the extractives sector use a specific tax hub for their investments, the more other MNEs will follow the pattern.

Table 9: Non-TSN and resource revenue mobilization

	Threshold>Q2(median)			Threshold>Q3(=75%)		
	[1]	[2]	[3]	[4]	[5]	[6]
TSN (ATT)	4.413***	4.108***	4.139***	2.943***	3.061***	3.379***
	(0.451)	(0.383)	(0.398)	(0.419)	(0.353)	(0.359)
Covariates	Yes	Yes	Yes	Yes	Yes	Yes
Control of corruption	No	No	Yes	No	No	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.886	0.923	0.926	0.875	0.912	0.917
Observations	651	651	620	651	651	620

Note: as for Table 8.

Source: authors' construction.

7.3 The effect of TSN over time

We highlight a time-varying, dynamic treatment effect (see Apeti 2023; Apeti and Edoh 2023 for similar analyses) to allow us to isolate the lagged effect of signing a tax treaty with an investment hub on resource revenue mobilization in source countries. The intuition behind this approach is that there is a potential time lag between the signing of a treaty with an investment hub and its possible effect on extractive revenue mobilization in source countries. To this end, we estimate ATTs for the year of first signature ($t=0$) and for the three years following the year of first signature of the tax treaty ($t=1, 2, 3, 4, 5$). The results, reported in Table 10, match the negative relationship in Table 8. They reveal the existence of a dynamic effect of signing a tax treaty with an investment hub on resource revenues in source countries. The negative effect appears as soon as the DTT is signed and increases over time (up to 3 years after signing). We can conclude that the effect of tax treaties on resource revenues is time sensitive—a finding that may reflect an increase in the number of DTTs over time or a delayed effect of a specific DTT.

Table 10: TSN effect over time

	Threshold>Q2(median)				Threshold>Q3(=75%)			
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
Year of signing BTT (*t+0*)	-1.543**				-2.122***			
	(0.609)				(0.532)			
First year after signing BTT (*t+1*)		-2.712***				-3.103***		
		(0.732)				(0.583)		
Two years after signing BTT (*t+2*)			-3.630***				-3.296***	
			(0.799)				(0.592)	
Three years after signing BTT (*t+3*)				-2.562***				-2.921***
				(0.849)				(0.623)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	651	620	589	562	651	620	589	562
R-squared	0.927	0.932	0.939	0.938	0.926	0.930	0.936	0.935

Note: as for Table 8.

Source: authors' construction.

7.4 Alternative measures of domestic revenue

We explore the sensitivity of our impact evaluation by replacing resource revenue with total government revenue. The results, reported in Table 11, show that signing a tax treaty with an investment hub has a negative relationship with total government revenue (Table B4 in Appendix

B shows similar analysis with non-resource revenue, but the coefficients are insignificant). However, signing DTTs with investment hubs increases direct taxes and corporate income taxes (see Tables B5 and B6), which could explain the positive effect of degree centrality on direct taxes and CIT. Association with an investment hub may incite increases in non-resource foreign investment and trade, which result in higher economic growth and widen the tax base, resulting in increased tax revenues. This result certainly matches the positive network effects posited by Hines (2010), who argues that tax hubs facilitate foreign investment in source countries and possibly contribute to growth (hence, revenue mobilization).

Table 11: TSN and total domestic revenue

	Threshold>Q2(median)			Threshold>Q3(=75%)		
	[1]	[2]	[3]	[4]	[5]	[6]
TSN (ATT)	-2.176***	-1.092	-1.287*	-2.345***	-1.573***	1.712***
	(0.711)	(0.715)	(0.741)	(0.580)	(0.575)	(0.602)
Covariates	Yes	Yes	Yes	Yes	Yes	Yes
Control of corruption	No	No	Yes	No	No	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.887	0.895	0.898	0.903	0.911	0.912
Observations	889	889	853	889	889	853

Note: as for Table 8.

Source: authors' construction.

7.5 Transmission channels: FDI inflows

Our results show that signing a tax treaty with an investment hub reduces resource revenue mobilization in source countries, but increases direct taxes and corporate income taxes, primarily through investment and trade. This dichotomy in effects begs the question: what is the primary channel through which tax treaties with investment hubs influence domestic revenues in source countries? As argued in Section 3, four transmission channels can be considered (one with potential positive effects and the other three with certain negative effects): (i) increased FDI induced by signing tax treaties with an investment hub; (ii) restrictions on permanent establishment rules, especially on the ability to tax specific types of services that represent parts of corporate structures (e.g. management and technical services); (iii) upper bounds on withholding tax rates on passive income; and (iv) limitations on (indirect) capital gains taxes. All four effects are exacerbated by treaty shopping. Cross-country data on withholding tax and capital gains tax revenues are unavailable for the entire sample period, so we restrict our analysis to the impact on FDI.

Given tax treaties' primary objective of promoting foreign investment, we analyse the impact of TSN on FDI inflows in resource-rich countries. As discussed in Section 4, increased FDI is expected to improve economic opportunities through possible facilitation of economic growth and an expansion of the tax base, hence more tax revenue (Camara 2023). Nevertheless, increased FDI from signing tax treaties with an investment hub may erode domestic revenues through tax optimization techniques (exacerbated by the complex corporate structures of resource MNEs), tax incentives for MNEs, tax exemptions, and stymied competitiveness of local domestic firms.

We estimate equation (7) with FDI as dependent variable and the dichotomous *TSN* variable used above. Our results, displayed in Table 12, show that signing a tax treaty with an investment hub increases FDI inflows in resource-rich countries, although our findings are non-robust (significant effects are obtained in just one model each). Our results demonstrate the attractiveness of investment and tax hubs in MNEs' investments, in line with several studies in the literature. Hines (2010) argues that investment hubs encourage foreign investment in source countries and

contribute to economic growth in source countries and elsewhere. Beer and Loeprick (2021) show that signing a tax treaty with an investment hub is not associated with additional investment, but treaty shopping has a small, positive effect on FDI. The authors suggest that the value of tax treaties in attracting investors remains indeterminate, particularly when investments tend to be geared towards natural resources or a specific country market. Although DTTs are not the only incentive to attract FDI, they may make a significant contribution.

Table 12: TSN and FDI inflows in resource-rich countries

	Threshold>Q2(median)			Threshold>Q3(=75%)		
	[1]	[2]	[3]	[4]	[5]	[6]
TSN (ATT)	1.681**	0.501	0.822	1.413**	0.288	0.597
	(0.688)	(0.708)	(0.748)	(0.589)	(0.591)	(0.631)
Covariates	Yes	Yes	Yes	Yes	Yes	Yes
Control of corruption	No	No	Yes	No	No	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.536	0.560	0.561	0.503	0.532	0.531
Observations	1062	1062	1015	1062	1062	1015

Note: as for Table 8.

Source: authors' construction.

8 Conclusion

Global increases in international trade and capital mobility have spurred an increase in bilateral taxation treaties, with more than 3,500 tax treaties and multiple regional agreements involving 164 countries worldwide currently extant. By assigning taxing rights to rival and competing jurisdictions and thereby eradicating double taxation, these treaties are meant to encourage cross-border investment. But the purported increases in foreign investment come at a cost in the form of revenue losses from restrictions on taxing certain services, withholding tax restrictions, and limits on the taxation of capital gains. These treaties might be exploited by large multinational companies in the extractives industry, who dominate the scene, given the huge capital outlays involved. For resource-rich source countries, these resources represent huge financial windfalls if adequately exploited and taxed. However, tax treaties and the attendant exploitation by MNEs pose strong challenges to revenue mobilization in source countries. While the MNEs provide the requisite financing, they structure their corporate activities—along the extractives value chain—to benefit from specific aspects of treaties in countries with large treaty networks (especially investment or tax hubs). Using standard fixed effects and system GMM techniques, we investigated the resource revenue impact of tax treaties for a sample of 83 resource-rich countries from 2000 to 2019 and report a strong and robust negative correlation between tax treaties and resource revenue mobilization.

The literature estimating the impact of tax treaties has typically consisted of standard dummy/ binary variables to model the existence of a tax treaty in a particular year, or measures of tax treaty aggressiveness (the ability of countries to secure lower withholding tax rates from source countries). Our analysis follows a different approach by looking at the pool of tax agreements as a network where two aspects are important: first, the number of treaties a country has within the total treaty network in the sample; second, the proximity of particular countries—measured as the shortest possible path between countries, i.e. where countries act as intermediate jurisdictions—within the total treaty network. We apply network theory in generating measures of treaty centrality that incorporate these key aspects, with the degree centrality index used to capture the first point

and betweenness centrality, closeness centrality, and eigenvector centrality indices used to capture the second point to varying degrees. Our analysis shows that the measures of centrality have a strong negative association with resource revenue mobilization (as well as other revenue aggregates).

An index that measures the proximity of a country to other countries in a treaty network is informative, since bilateral tax treaties inherently posit interconnections across countries. The betweenness centrality index explicitly captures this concept, as it measures the number of times a country serves as a key broker between any other pair of countries, demonstrating the importance of intermediary countries (investment or tax hubs) for indirect investments (especially because the index also inherently incorporates related treaty networks). This is important in the tax treaty literature, as MNEs seek to exploit mismatches in treaty withholding tax rates and other provisions (intermediate countries have been known to tax income lightly), an activity known as treaty shopping. Treaty shopping is perpetuated by intermediate countries, which permit corporate activities to be structured so as to yield benefits from specific aspects of treaties across jurisdictions; and treaty shopping has been shown to exacerbate revenue losses from the signing of tax treaties.

Using the betweenness centrality index, our analysis estimates the impact of signing a tax treaty with an investment hub on resource revenue mobilization in source countries. We split all countries in the network at the median and third quartile of their betweenness centrality index, and countries above the threshold are classified as betweenness counties (investment and/or tax hubs). Treatment is signing a treaty with an investment hub for a given resource-rich source country in our sample. We employ the entropy balancing method and find that signing a tax treaty with an investment hub has non-negligible negative effects on resource revenue mobilization in source countries. This points to MNEs structuring their corporate investments to benefit from the light taxation offered by investment or tax hubs, with a net effect of eroding resource revenues in source countries. We posit FDI to be an important channel through which tax treaties with investment hubs (hence, treaty shopping) will reduce revenues in source countries. We show a positive, albeit mild, non-robust association between signing a tax treaty with an investment hub and FDI inflows. Our findings largely match what has been espoused and proven in the literature: the effects of treaty shopping on FDI are positive and tenuous, at best, while the effects on revenue mobilization are non-negligibly deleterious.

The overwhelming presence of MNEs in the extractives sector is unsurprising: the financial outlays and technical expertise needed to develop natural resources cannot be matched by cash-strapped and capacity-constrained source countries or their domestic firms. The MNEs, however, present strong challenges to optimal revenue mobilization from extractives development. Tax treaty policy in resource-rich countries, where such policy exists, has not fully appreciated the importance of the resource in drafting policy. While it has been generally advised that an overall cost–benefit analysis be done, most tax treaty policy in source countries has been tangential to overall tax policy. Our analysis shows that failure to incorporate the importance of the natural resources sector into broader treaty policy leaves source countries exposed to huge revenue losses, with no significant countervailing sustained increase in foreign investment.

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Appendix A: Data

List of baseline countries

Albania, Algeria, Angola, Azerbaijan, Belize, Benin, Bhutan, Botswana, Burkina Faso, Cambodia, Cameroon, Cape Verde, Central African Republic, Chad, China, Congo, Dem. Rep., Congo, Rep., Costa Rica, Côte d'Ivoire, Dominican Republic, Ecuador, Egypt, Equatorial Guinea, Eritrea, Eswatini, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Guyana, Honduras, India, Indonesia, Iran, Islamic Rep., Iraq, Jordan, Kazakhstan, Kenya, Kyrgyz Republic, Lao PDR, Lesotho, Liberia, Madagascar, Malawi, Malaysia, Mali, Mauritania, Mexico, Mongolia, Morocco, Mozambique, Myanmar, Namibia, Nicaragua, Niger, Nigeria, North Macedonia, Papua New Guinea, Russian Federation, Rwanda, Sierra Leone, Solomon Islands, Somalia, South Africa, South Sudan, Sudan, Suriname, Syrian Arab Republic, Tajikistan, Tanzania, Timor-Leste, Togo, Tunisia, Türkiye, Turkmenistan, Uganda, Ukraine, Uzbekistan, Viet Nam, Yemen, Rep., Zambia, Zimbabwe

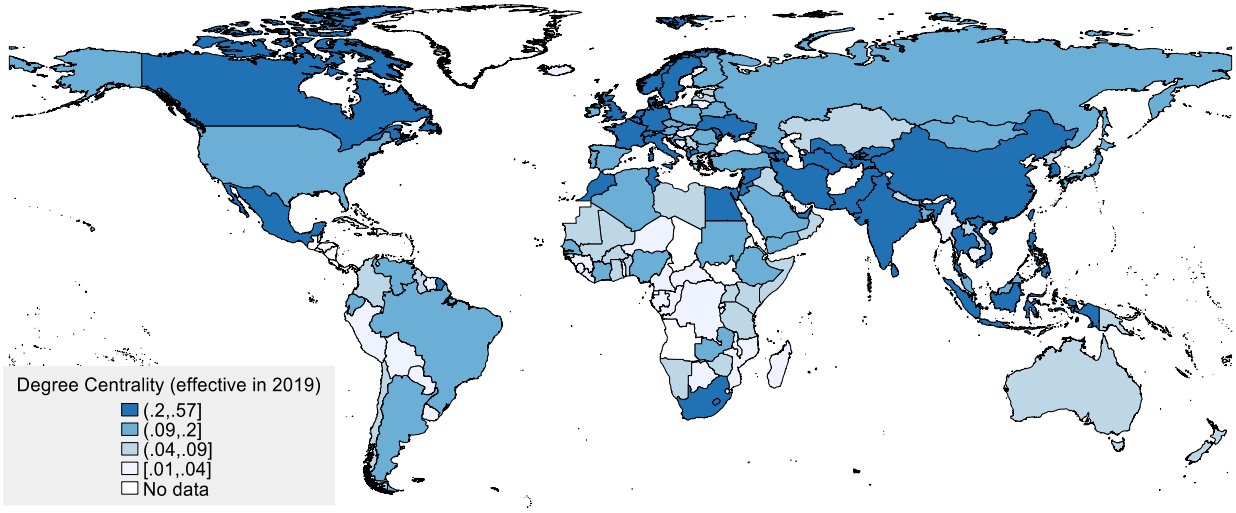
List of countries coded with betweenness index >Q2 (median, Me):	
Albania, Algeria, Argentina, Armenia, Azerbaijan, Bangladesh, Belarus, Benin, Brazil, Bulgaria, China, Colombia, Cote d'Ivoire, Ecuador, Egypt, Ethiopia, Georgia, Grenada, Guinea-Bissau, Guyana, India, Indonesia, Iran, Jamaica, Jordan, Kenya, Kyrgyz, Lebanon, Libya, Malaysia, Mali, Mauritania, Mauritius, Mexico, Moldova, Mongolia, Morocco, Mozambique, Nigeria, North Macedonia, Pakistan, Papua New Guinea, Philippines, Romania, Russia, Senegal, Sri Lanka, Sudan, Syria, Tajikistan, Thailand, Tunisia, Türkiye, Turkmenistan, Uzbekistan, Viet Nam, Zambia, Zimbabwe	
List of treated baseline countries (e.g. that signed DTT with at least one betweenness country for a given year above):	**List of treated baseline countries (e.g. that have not signed DTT with at least one betweenness country for a given year):**
Albania, Algeria, Azerbaijan, Bhutan, Botswana, Burkina Faso, Cameroon, Cape Verde, China, Congo, Rep., Côte d'Ivoire, Ecuador, Egypt, Arab Rep., Ethiopia, Gabon, Guinea, India, Indonesia, Iran, Islamic Rep., Iraq, Jordan, Kazakhstan, Kenya, Kyrgyz, Republic, Lao PDR, Lesotho, Madagascar, Malaysia, Mali, Mauritania, Mexico, Mongolia, Morocco, Mozambique, Myanmar, Namibia, Nigeria, North Macedonia, Russian Federation, South Africa, Sudan, Swaziland, Syrian, Arab Rep., Tajikistan, Tunisia, Turkmenistan, Uganda, Ukraine, Uzbekistan, Viet Nam, Zambia	Angola, Belize, Benin, Cambodia, Central African Republic, Chad, Congo, Dem. Rep., Costa Rica, Dominican Republic, Equatorial Guinea, Eritrea, Gambia, Ghana, Guinea-Bissau, Guyana, Honduras, Liberia, Malawi, Nicaragua, Niger, Papua New Guinea, Rwanda, Sierra Leone, Solomon Islands, Somalia, South Sudan, Suriname, Tanzania, Timor-Leste, Togo, Yemen Republic, Zimbabwe

Source: authors' construction.

List of countries coded with betweenness index >Q3 (3rd quartile)	
Albania, Algeria, Argentina, Armenia, Azerbaijan, Brazil, China, Colombia, Côte d'Ivoire, Egypt, Georgia, Grenada, India, Indonesia, Iran, Jamaica, Jordan, Malaysia, Mauritius, Mexico, Moldova, Morocco, North Macedonia, Pakistan, Papua New Guinea, Philippines, Romania, Russia, Senegal, Sri Lanka, Syria, Thailand, Tunisia, Ukraine, Uzbekistan, Viet Nam	
List of treated baseline countries (e.g. that signed DTT with at least one betweenness country for a given year):	**List of treated baseline countries (e.g. that have not signed DTT with at least one betweenness country for a given year):**
Albania, Algeria, Azerbaijan, Bhutan, Botswana, Burkina Faso, Cameroon, Cape Verde, China, Congo Rep., Côte d'Ivoire, Ecuador, Egypt Arab Rep., Gabon, Guinea, India, Indonesia, Iran, Islamic Rep., Iraq, Jordan, Kazakhstan, Kyrgyz Rep., Lao PDR, Lesotho, Madagascar, Malaysia, Mali, Mauritania, Mexico, Mongolia, Morocco, Mozambique, Myanmar, Namibia, Nigeria, North Macedonia, Russian Federation, South Africa, Sudan, Swaziland, Syrian Arab Rep., Tajikistan, Tunisia, Turkmenistan, Uganda, Ukraine, Uzbekistan, Viet Nam, Zambia	Angola, Belize, Benin, Cambodia, Central African Republic, Chad, Congo Dem. Rep., Costa Rica, Dominican Republic, Equatorial Guinea, Eritrea, Ethiopia, Gambia, Ghana, Guinea-Bissau, Guyana, Honduras, Kenya Liberia, Malawi, Nicaragua, Niger, Papua New Guinea, Rwanda, Sierra Leone, Solomon Islands, Somalia South, Sudan, Suriname, Tanzania, Timor-Leste, Togo, Yemen Rep., Zimbabwe

Source: authors' construction.

Figure A1: Betweenness centrality index of countries' tax treaties network in 2019



Source: authors' construction.

Table A1: Summary statistics

Variable	Mean	Std. Dev.	Min.	Max.	N
Total resource revenue (% GDP)	5.97	10.22	0.00	79.11	982
Total domestic revenue (% GDP)	21.37	10.35	1.98	80.82	1,406
Total non-resource revenue (% GDP)	13.81	6.71	0.90	35.03	978
Direct taxes (% GDP)	4.50	2.75	0.13	16.19	1,128
Indirect taxes (% GDP)	8.39	4.88	0.19	48.62	1,316
TSN treatment (dummy)	0.31	0.46	0.00	1.00	1,660
Degree centrality (units)	19.58	19.85	1.01	104.38	1,371
Degree centrality (index)	0.11	0.11	0.01	0.58	1,371
Betweenness centrality (index)	0.45	0.07	0.30	0.70	1,371
Closeness centrality (index)	0.06	0.05	0.00	0.24	1,371
Eigenvector centrality (index)	0.01	0.04	0.00	0.38	1,371
Log GDP per capita (USD)	7.32	1.07	4.70	9.90	1,626
Total resource rents (% GDP)	12.09	12.40	0.02	87.58	1,612
Inflation (CPI % annual)	8.74	23.81	-10.07	513.91	1,523
Trade (% GDP)	76.37	33.38	1.22	220.41	1,493
Industrial value added (% GDP)	28.97	12.77	3.24	84.80	1,586
Fuel and metals exports (% exports)	30.40	30.76	0.00	99.96	1,235
Democratic risk	3.40	1.41	0.00	6.00	1,080
External conflict risk	9.61	1.52	2.13	12.00	1,080
Investment profile risk	7.33	1.79	1.00	11.50	1,080
Socioeconomic conditions risk	4.05	1.85	0.00	10.25	1,080
Control of corruption	-0.67	0.58	-1.85	1.64	1,567

Note: variable definitions and sources are given in Table A2.

Source: authors' construction.

Table A2: Variable definitions and sources

Variable	Description	Source
Total resource revenue	Sum of natural resource tax and natural resource non-tax revenue, expressed as a percentage of GDP	GRD
Total domestic revenue	Sum of total tax and total non-tax revenue, excluding social contributions and official development assistance grants, expressed as a percentage of GDP	GRD
Total non-resource revenue	Total taxes less resource taxes plus non-tax revenue (excluding the resource component) plus social contributions, expressed as a percentage of GDP	GRD
Direct taxes	Sum of taxes on income, profits and capital gains, taxes on payroll and workforce, and property tax, expressed as a percentage of GDP	GRD
Indirect taxes	Sum of taxes on goods and services and taxes on international trade, expressed as a percentage of GDP	GRD
CIT [PIT]	Taxes on corporations [PIT comprises 'taxes on individuals' payroll and workforce'], expressed as a percentage of GDP	GRD
Trade taxes	Total taxes on international trade, expressed as a percentage of GDP	GRD
Good & services taxes	The sum of sales taxes/VAT and excises, expressed as a percentage of GDP	GRD
Degree centrality	Density of a given country measured by the ratio of the effective links (those in place) to the potential links of the country or as the number of links of a given country	Authors' calculation
Betweenness centrality	Number of times a given node (country) is the shortest path (geodesic) between any other pair of nodes (countries) in the graphs	Authors' calculation
Closeness centrality	Inverse of the average shortest distance between the country and all other countries (vertices) in the network	Authors' calculation
Eigenvalue centrality	Proportional to the sum of the centrality indices of its neighbours	Authors' calculation
GDP growth (%)	Annual percentage growth rate of GDP at market prices based on constant local currency	WDI
Log GDP per capita	GDP per capita is the gross domestic product divided by population in constant 2015 US$. We use the natural logarithm in estimation.	WDI
Total resource rents	Sum of oil rents, natural gas rents, coal (hard and soft) rents, mineral rents, and forest rents, expressed as a percentage of GDP	WDI
Inflation (CPI % annual)	Annual percentage change in the cost to the average consumer of acquiring a basket of goods and services that may be fixed or changed at specific intervals, such as yearly	WDI
Trade	Trade volume (exports plus imports) as a percentage of GDP	WDI
Industrial value added	Value added in mining, manufacturing, construction, electricity, water, and gas, expressed as a percentage of GDP	WDI
Fuel and metals exports (% exports)	Mineral fuels, lubricants, and related materials, expressed as a percentage of total merchandise exports	WDI
Democratic risk	Measure of how responsive government is to its people, on the basis that the less responsive it is, the more likely it is that the government will fall—peacefully in a democratic society, but possibly violently in a non-democratic one	ICRG
External conflict risk	Assessment of the risk to the incumbent government of foreign action or violent external pressure	ICRG
Investment profile risk	Assessment of factors affecting the risk to investment that are not covered by other political, economic, and financial risk components	ICRG
Socioeconomic conditions risk	Assessment of the socioeconomic pressures at work in society that could constrain government action or fuel social dissatisfaction	ICRG
Control of corruption	Perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as 'capture' of the state by elites and private interests	WGI

Note: CPI = Consumer Price Index; GRD = Government Revenue Dataset; ICRG = International Country Risk Guide; WDI = World Development Indicators.

Source: authors' construction.

Appendix B: Additional results and robustness

Table B1: Baseline results—FE

Dependent variable: resource revenue (% GDP)	**[1]**	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**
Degree centrality	-0.098***	-0.108***	-0.070**	-0.093***	-0.122***	-0.093***
	(0.031)	(0.034)	(0.033)	(0.035)	(0.034)	(0.033)
Log GDP per capita	1.891***	2.124***	2.608***	2.122***	2.008***	1.837***
	(0.334)	(0.379)	(0.367)	(0.380)	(0.376)	(0.306)
Resource rents (% GDP)	0.320***	0.403***	0.399***	0.403***	0.393***	0.329***
	(0.025)	(0.032)	(0.030)	(0.032)	(0.032)	(0.025)
Inflation (CPI %)	-0.055**	-0.055**	-0.014	-0.062**	-0.052*	-0.067***
	(0.023)	(0.027)	(0.027)	(0.027)	(0.027)	(0.024)
Trade (% GDP)	0.012	0.001	-0.007	-0.002	0.002	0.010
	(0.010)	(0.013)	(0.012)	(0.013)	(0.013)	(0.010)
FDI (% GDP)	-0.144***	-0.153***	-0.150***	-0.148***	-0.160***	-0.147***
	(0.026)	(0.030)	(0.029)	(0.030)	(0.030)	(0.026)
Democratic risk		0.536**				
		(0.247)				
External conflict risk			1.483***			
			(0.223)			
Investment profile risk				0.316*		
				(0.166)		
Socioeconomic conditions risk					0.711***	
					(0.180)	
Control of corruption						0.423
						(0.698)
R-squared	0.335	0.418	0.468	0.416	0.433	0.355
Observations	575	450	450	450	450	548
Countries	39	34	34	34	34	39

Note: results are for the sample of countries with a resource rents-to-GDP ratio greater than 10%. GDP = gross domestic product; FDI = foreign direct investment; CPI = consumer price index; FE = fixed effects. ***, **, and * denote statistical significance at 1, 5 and 10% levels, respectively. Standard errors are reported in parentheses.

Source: authors' construction.

Table B2: Baseline results—GMM

Dependent variable: resource revenue (% GDP)	**[1]**	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**
Dependent variable (lagged)	0.570*** (0.088)	0.345*** (0.055)	0.642*** (0.033)	0.522*** (0.013)	0.393*** (0.053)	0.682*** (0.025)
Degree centrality	-0.073** (0.036)	-0.097** (0.049)	-0.024** (0.012)	-0.033*** (0.009)	-0.113** (0.054)	-0.021** (0.010)
Log GDP per capita	2.978** (1.339)	3.231*** (1.067)	0.664*** (0.243)	0.734*** (0.188)	2.086*** (0.760)	0.470** (0.191)
Resource rents (% GDP)	0.179*** (0.059)	0.378*** (0.075)	0.183*** (0.020)	0.291*** (0.014)	0.407*** (0.055)	0.099*** (0.025)
Inflation (CPI %)	0.015 (0.030)	-0.098* (0.054)	-0.015 (0.010)	-0.026** (0.011)	-0.094** (0.045)	-0.006 (0.012)
Trade (% GDP)	-0.022 (0.015)	-0.094 (0.067)	0.023*** (0.009)	0.012 (0.009)	-0.110** (0.051)	0.015** (0.006)
FDI (% GDP)	-0.018 (0.021)	0.035 (0.089)	-0.413*** (0.037)	-0.437*** (0.051)	-0.068 (0.069)	-0.269*** (0.061)
Democratic risk		-0.243 (0.346)				
External conflict risk			0.033 (0.100)			
Investment profile risk				0.258*** (0.082)		
Socioeconomic conditions risk					0.853** (0.403)	
Control of corruption						-0.328 (0.386)
Observations	710	539	539	539	539	675
Countries	49	42	42	42	42	47
Instruments	16	16	24	28	17	21
Chi2 *p*-value	0.000	0.000	0.000	0.000	0.000	0.000
Hansen *J* *p*-value	0.192	0.211	0.585	0.384	0.392	0.622
AR (1) *p*-value	0.039	0.066	0.059	0.057	0.059	0.058
AR (2) *p*-value	0.181	0.261	0.246	0.292	0.323	0.368
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

Note: results are for the sample of countries with a resource rents-to-GDP ratio greater than 10%. GDP = gross domestic product; FDI = foreign direct investment; CPI = consumer price index; FE = fixed effects. ***, **, and * denote statistical significance at 1, 5 and 10% levels, respectively. Standard errors are reported in parentheses. In all specifications, the null hypothesis for the lack of first-order (AR (1)) serial correlation in the first-differenced error terms is rejected, while the null hypothesis for the lack of second-order (AR (2)) serial correlation cannot be rejected. The number of instruments is limited to avoid over-fitting the model (as expected, the number of instruments is less than the number of countries). In addition, the *p*-value on the Hansen *J* test for overidentifying restrictions fails to reject the null hypothesis that the model is correctly specified, and the instrument set is valid.

Source: authors' construction.

Table B3: BTTs and disaggregated revenue aggregates

Dependent variable: (% GDP)	Indirect taxes [1]	Direct taxes [2]	CIT [3]	PIT [4]	Trade taxes [5]	G&S taxes [6]
Degree centrality	0.010	0.023***	0.025***	0.011***	-0.019***	0.027***
	(0.007)	(0.007)	(0.007)	(0.003)	(0.005)	(0.006)
GDP growth (%)	0.003	-0.009	-0.016	-0.005	0.004	-0.018*
	(0.013)	(0.013)	(0.012)	(0.006)	(0.009)	(0.011)
Resource rents (% GDP)	-0.041***	0.020*	0.089***	-0.013**	-0.017**	-0.022**
	(0.012)	(0.011)	(0.012)	(0.005)	(0.008)	(0.010)
Inflation (CPI %)	-0.016**	-0.010	-0.009*	0.001	0.002	-0.018***
	(0.008)	(0.007)	(0.005)	(0.003)	(0.005)	(0.006)
Trade (% GDP)	0.018***	0.011***	0.002	0.008***	0.001	0.016***
	(0.004)	(0.004)	(0.004)	(0.002)	(0.003)	(0.004)
FDI (% GDP)	0.057***	0.034***	0.013	0.008*	0.007	0.036***
	(0.010)	(0.011)	(0.013)	(0.004)	(0.007)	(0.008)
Democratic risk	0.241***	0.159**	0.020	0.143***	0.070	0.197***
	(0.077)	(0.075)	(0.063)	(0.036)	(0.055)	(0.067)
R-squared	0.107	0.069	0.208	0.089	0.033	0.107
Observations	768	642	381	592	751	747
Countries	53	47	33	48	54	54

Note: as for Table 1.

Source: authors' construction.

Table B4: TSN and non-resource revenues

	Threshold>Q2(median)			Threshold>Q3(=75%)		
	[1]	[2]	[3]	[4]	[5]	[6]
TSN (ATT)	0.178	-0.314	-0.442	0.045	-0.349	-0.660*
	(0.487)	(0.497)	(0.517)	(0.379)	(0.376)	(0.396)
Covariates	Yes	Yes	Yes	Yes	Yes	Yes
Control of corruption	No	Yes	Yes	No	No	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.915	0.920	0.921	0.927	0.933	0.934
Observations	634	634	606	634	634	606

Note: the table presents the effects of signing a tax treaty with an investment hub (the treatment) on resource-rich source countries. Control variables are those included in Table 7. ***, **, and * denote significance at 1, 5, and 10% levels, respectively. Results using treatment based on the first quartiles (i.e. threshold>25%) are the same as those for the median, hence not reported.

Source: authors' construction.

Table B5: TSN and direct taxes

	Threshold>Q2(median)			Threshold>Q3(=75%)		
	[1]	[2]	[3]	[4]	[5]	[6]
TSN (ATT)	0.688***	0.550***	0.591***	0.557***	0.474***	0.414**
	(0.188)	(0.197)	(0.208)	(0.160)	(0.164)	(0.175)
Covariates	Yes	Yes	Yes	Yes	Yes	Yes
Control of corruption	No	Yes	Yes	No	No	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.866	0.870	0.867	0.891	0.894	0.893
Observations	880	880	842	880	880	842

Note: as for Table B4.

Source: authors' construction.

Table B6: TSN and CIT

	Threshold>Q2(median)			Threshold>Q3(=75%)		
	[1]	[2]	[3]	[4]	[5]	[6]
TSN (ATT)	0.508***	0.557***	0.624***	0.584***	0.637***	0.600***
	(0.190)	(0.196)	(0.203)	(0.174)	(0.174)	(0.185)
Covariates	Yes	Yes	Yes	Yes	Yes	Yes
Control of corruption	No	Yes	Yes	No	No	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.752	0.761	0.761	0.751	0.760	0.759
Observations	750	750	714	750	750	714

Note: as for Table B4.

Source: authors' construction.