CORTAX 2019 Updated calibration and baseline results

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Bratta, B.
Pycroft, J.
Stoehlker, D.

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Abstract

CORTAX is a macroeconomic model that focuses on corporate taxation and is used extensively for European Commission policy assessments. As a macroeconomic model, it simulates variables such as GDP, investment and employment, while being especially notable for its focus on corporate income taxation (CIT). It models the key aspects of CIT, such as multinational profit shifting, investment decisions, loss compensation, and debt-equity financing. CORTAX is versatile and can be used to examine different aspects of CIT, such as adjusting or harmonizing the CIT rate or base, addressing debt bias in CIT, and consolidation of the multinational CIT base.

CORTAX is a multi-country model, covering all EU Member States, selected partner countries, and a tax haven. The general equilibrium framework of the model captures the interactions between different economic actors, including those between multinational headquarters and foreign subsidiaries.

This calibration updates the model to 2019. This paper outlines the model structure, and explains the methodology used to arrive at the new baseline, including explaining the choices of data sources and parameters. The paper provides key summary results that serve as both a description and a validation of the model, and also serves as a reference for future work carried out using CORTAX 2019.

1 Introduction

Corporate taxation is both an important source of government revenue and a significant factor shaping corporate behaviour, including investment and financing decisions. Furthermore, the complexity of corporate tax systems and the ability of multinational corporations to shift profits to low-tax jurisdictions have raised concerns about fairness, sustainability, and the erosion of the tax base. Certain forms of tax planning can be considered unfair, in the sense that they shift the tax burden onto other taxpayers. The issue of economic efficiency arises as companies may shift productive resources due to their corporate tax obligations, or indeed, due to opportunities to reduce them. As such, corporate taxation is a critical issue for policymakers and businesses.

CORTAX is an economic model used to simulate the effects of corporate tax reform on corporate behaviour, government revenue, and the economy as a whole. It can provide insights for policymakers and researchers, who seek to evaluate the effects of corporate tax policies on the economy. In addition to simulating macroeconomic variables, such as GDP, investment, and employment, the model is also designed to capture key aspects of corporate income taxation, such as multinational profit shifting, investment decisions, loss compensation, and debt-equity financing. The model has been designed to examine potential policy reforms, such as adjusting or harmonizing the CIT rate or base, addressing debt bias in CIT, and consolidation of the multinational CIT base.

CORTAX was originally built by economists at the Centraal Planbureau (CPB), Netherlands, (Bettendorf and van der Horst, 2006) drawing on the earlier OECDTAX model (Sorensen, 2001). CORTAX has been used in studies of corporate tax reform including corporate tax harmonisation and the common consolidated corporate tax base (CCCTB; Bettendorf et al., 2010a; Bettendorf et al., 2010b, Álvarez-Martínez et al., 2016a), the debt bias in corporate taxation (de Mooij and Devereux, 2011) and the impact of corporate taxation on the labour market (Bettendorf et al., 2009a). Subsequent studies addressed the impacts of varying corporate tax rates (Álvarez-Martínez et al., 2019) and produced estimates of the size of corporate tax base erosion and profit shifting (Álvarez-Martínez et al., 2021). It has also been used in a number of European Commission Impact Assessments ([1]) starting with the proposal for a Common Consolidated Corporate Tax Base (CCCTB) in 2011 (European Commission, 2011). This proposal was updated and substantially revised in a subsequent Impact Assessment (European Commission, 2016). CORTAX simulations then contributed to the Impact Assessments relating to the Fair Taxation of the Digital Economy (European Commission, 2018) and the Debt-Equity Bias Reduction Allowance (DEBRA; European Commission 2022).

This JRC Technical Report outlines an updated calibration for CORTAX to a base year of 2019. The choice of 2019 is due to lag in the availability of certain variables, and the choice to avoid the exceptional years of 2020 and 2021 due to the COVID crisis, as CORTAX aims to reflect a stable, long-run economy. CORTAX 2019 models 30 countries, namely each of the EU 27, the UK, the USA, and Japan. Additionally, there is a notional tax haven, to which a proportion of profits can be shifted.

To explain the context in which the calibration was undertaken, this report first outlines the structure of CORTAX in Section 2. This section highlights the relationships between the key agents in CORTAX and salient features of the model. Section 3 details the data that are used and their sources, followed by the parameters used, which are either estimated or selected based on the literature. Section 4 presents selected baseline characteristics of the model, such as key elasticities by country. Section 5 concludes with a discussion of potential future developments of the model.

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1 European Commission Impact Assessments are ex-ante studies carried out prior to finalising a proposal for a new law. They seek to "examine whether there is a need for EU action and analyse the possible impacts of available solutions".

2 Structure of CORTAX

CORTAX is designed to simulate the economic effects of tax policy reforms at the national and international level. The model accounts for the transactions between firms (distinguishing between domestic firms and multinational enterprises), households, and governments. Each country features interactions between consumption, savings, production, and public finances. The model incorporates international trade in goods markets, investment by multinational enterprises, international capital flows, and intermediate inputs within multinationals (which serve as a vehicle to model transfer pricing across borders).

Firms are divided into three categories: MNE headquarters, which are linked to an MNE subsidiary in each of the other countries, and domestic firms that only operate in their home country. All firms maximise their profits, with MNEs optimising their global profits, including engaging in profit shifting activities across borders. All firms have some access to a notional tax haven, where they shift some of their profits, though the amount of profits shifted is smaller for domestic firms. All firms face compliance costs of fulfilling their corporate tax obligations.

CORTAX is a multi-country model with a full calibration for each of the 30 countries modelled (the EU Member States, the UK, the USA and Japan). The general equilibrium framework of the model captures the interactions between different economic actors, including those between multinational headquarters and foreign subsidiaries. The model solves for the long-run steady state equilibrium producing various macroeconomic aggregates, such as GDP, total household consumption, investment, and tax revenues. It is designed to simulate reforms in the corporate tax system, such as changes in the tax rates, tax base, harmonisation across countries, and consolidation of the tax base.

The following sub-sections outline the components of CORTAX. We focus on describing the behaviour of the economic relationships ([2]).

2.1 Households

Households maximise their lifetime utility subject to their lifetime budget constraint. Households live for two generations: young (age 20 – 59) and old (age 60 – 99). Households receive utility from consumption and disutility from working. Young households choose their levels of work, consumption and savings so as to maximise their inter-temporal utility. In the process, they account for transfers received from the government, taxes on income and consumption paid to the government, and the interest rate received on their savings.

Households prefer a savings portfolio that include both bonds and stocks. They are imperfect substitutes, with stocks offering a higher rate of return than bonds. The gross return to bonds and stocks are determined on world markets.

CORTAX calculates a welfare change as part of its output results. The value shown in the difference in transfers that would need to be received by young households (positive or negative) to compensate for the change in lifetime utility (the compensating variation).

2.2 Firms and production

CORTAX features three firm types: domestic firms, multinational headquarters and multinational subsidiaries. Each country has one representative domestic firm and one multinational headquarters. This headquarter owns a representative subsidiary in each of the other countries ([3]). Firms maximise their value subject to the production function and accumulation constrains. The firms' value is equal to the net present value of the flow of future profits.

Production in all firms involves labour, capital, and a fixed, location-specific production factor (which can be considered as representing land). Labour and capital are imperfect substitutes, and so are combined in the model within a constant elasticity of substitution (CES) function to produce value-added. Value-added is combined with the fixed factor in a Cobb-Douglas function to produce the final output. Note that the existence of the fixed factor ensures that part of the corporate tax falls on rents.

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[2] Readers interested in the model equations are referred to Bettendorf and van der Horst (2006), Bettendorf et al. (2009) and Álvarez-Martínez et al. (2016) for further details.

[3] As explained below, when the FDI stocks between an investor and destination country, that multinational subsidiary is not modelled.

In the case of multinational subsidiaries, there is another factor of production, namely an intermediate input, which is purchased from the multinational headquarters. For subsidiaries, this intermediate input is included in the Cobb-Douglas production function with value-added and the fixed factor. The intermediate input is a crucial link between the multinational headquarters and each subsidiary. By manipulating the price of this intermediate input, the multinational can shift a portion of its profits to lower tax jurisdictions, as explained in the next sub-section.

Aggregate production within each country in the total production by the domestic firm, the multinational headquarters and all the subsidiaries located in that country.

2.3 Profit shifting: between countries and to the tax haven

Profit shifting between countries is modelled between multinational headquarters and their associated subsidiaries. The subsidiaries purchase an intermediate input from the headquarters, for which the arms-length price is taken to be one. Multinationals deviate from this price in order to shift profits either to the subsidiary (a price below one) or to the headquarters (a price above one). This allows the multinational headquarters to move a portion of its taxable base to or from the subsidiary country. The benefit from deviating from the arms-length price depends on the difference between the statutory corporate tax rates between the location of the headquarters and subsidiary. The cost of deviating is taken to be a convex function, such that profit shifting becomes increasingly costly at the margin. The cost function reflects the reality that there are limits and risks for the firm, the more it deviates from the arms-length price, and also mathematically ensures that the model reaches an interior solution.

The model allows firms to shift part of their tax base to a tax haven. This is modelled as a separate channel for profit shifting than transfer pricing between multinational headquarters and subsidiaries outlined above. The extent to which this occurs is parameterised in line with the literature, in particular the elasticity estimates of a meta-regression study with multinational firms considerably more able to take advantage of tax haven than domestic firms (Heckemeyer & Overesch, 2013). Firms in the model recognise that not all of their CIT tax base will be subject to the statutory tax rate, meaning that their effective statutory tax rate is reduced.

2.4 Compliance Costs

The model incorporates the compliance costs incurred by firms in meeting their corporate tax obligations. These costs are measured in terms of the number of new workers required to fulfil these tasks. Effectively, this results in two types of labour: the vast majority of workers who produce output and a small share of workers who handle tax administration. The latter group is calculated as a fixed proportion of the productive labour force and increases in proportion to the size of the firm's payroll.

2.5 Corporate Investment and FDI

Foreign direct investment (FDI) refers to the equity-financed part of foreign capital (i.e., not including the debt-financed part). The initial size of subsidiaries is calibrated using data on the bilateral FDI stock (the methodology is explained in more detail below).

Corporate investments can be funded through retained earnings or by issuing bonds, as CORTAX does not permit the issuance of new shares. The decision on the source of finance is determined by comparing the after-tax costs of debt and equity. The model considers the marginal cost of debt to increase as the debt share rises, resulting in an optimal debt ratio and aligning with empirical evidence that firms typically choose a mix of debt and equity financing.

2.6 Cost of capital

The main channel through which corporate tax impacts investment is through the cost of capital. The effective marginal tax rate (EMTR) quantifies the impact of corporate taxes by calculating the cost of capital with and without taxes, and expressing this as a percentage of the tax-inclusive cost of capital. It effectively summarises several aspects of the tax system, such as the statutory tax rate, depreciation allowances, and the value of losses carried forward. It typically has a positive value, indicating the corporate tax increases the cost of capital.

2.7 Losses and loss carry forward

Firms can exist in a good state, where they make positive profits, or a bad state, where they make losses. In order to represent both states in a representative firm, CORTAX takes a share of production to be from a good state and a (smaller) share of production to be from a bad state. Firms are aware of their expected productivity, i.e., the probability of each outcome multiplied by the productivity in each state, and make decisions on this basis.

The existence of losses impacts the corporate tax base, because losses carried forward are permitted as a deduction from the tax base (in the next period).

2.8 Public Sector

Governments in CORTAX perform the functions of collecting tax revenue, spending on government consumption, providing transfers to households, and servicing public debt. Taxes include income tax on labour, consumption tax on spending, taxes on dividends, capital gains and interest, and income tax on corporations. CORTAX allows for the balancing of the government budget in response to simulations on particular tax categories, transfers or expenditure, or alternatively, not to balance the government budget.

2.9 Equilibrium

All markets solve to equilibrium in CORTAX. The representative homogenous good is traded in a perfectly competitive world market. Therefore countries cannot exert market power and their terms of trade are fixed. The price of this good is the "numeraire" in the model. In the asset market, bonds and equities of different origins are perfect substitutes and are freely traded across borders. The gross rates of return to these assets is therefore fixed at the world level. Holding assets as debt or equity are imperfect substitutes for households. The labour market is balanced by the supply and demand, and so total employment adjusts in the model. Labour is immobile across borders, and therefore, wages are determined at the country level. The balance of payments must hold (be equal to zero) for each country, and therefore, the current account equals the change in the net foreign asset position.

3 Calibration of CORTAX

The model uses data from various established sources, including Eurostat, the OECD, UN, ZEW-Mannheim, and company-level information from the Bureau van Dijk Orbis database. This section provides an overview of the exact data sources as well as how the data is being processed before being used as model inputs. Section 3.1 covers data sources for critical CORTAX variables and section 3.2 summarizes parameter values.

3.1 Data

The update to 2019 data has been carried out in a consistent way with the previous updates (Álvarez-Martínez et al., 2016) while at the same time improving the accuracy of the data by using novel datasets not yet available or not complete enough in 2016. This section is organised as follows. Sub-section 3.1 provides information related to data sources of CORTAX variables, including Labour Force Statistics (sub-section 3.11), bilateral FDI stock data (3.1.2), country-level tax revenue data (3.1.3), country-level CIT regime characteristics (3.1.4), CIT-specific compliance costs for firms (3.1.5), government tax collection costs (3.1.6), and the calibration of formulary apportionment keys (3.1.6).

3.1.1 Labour force statistics

The labour supply enters the model as a share of a notional maximum labour supply, which is calculating in the following way. The share of the population employed is computed as the active labour force, taken from AMECO data, divided by the number of people employed, taken from United Nations Population Statistics.

The number of hours per worker is computed from AMECO data, taking the hours worked by employees and self-employed divided by the number of employees and self-employed. The share of hours worked is this figure divided by a notional maximum hours worked ([4]).

The labour supply in the model is calculated as the product of these two shares (which gives a value between 0 and 1), i.e.:

$$labourSupply = sharePopulationEmployed \ \times shareHoursWorked$$

The wage level is calculated from macroeconomic statistics taken from Eurostat national accounts data. The share of value added to labour (adjusted to include value-added to both employees and self-employed) multiplied by the total value added (i.e., GDP at factor cost) must equal the average wage level multiplied by the labour supply, i.e.:

$$wageLevel = \frac{shareVAtoLabour \times GDP_{factorCost}}{labourSupply}$$

From the United Nations Population Statistics we can infer also the average population growth rate.

3.1.2 FDI Stock Data

Information on bilateral FDI stocks in 2019 is based on data from the IMF's Coordinated Direct Investment Survey (CDIS) data. The dataset contains for all country pairs stock positions of investing and receiving countries. Missing FDI data values are filled in manually using the data on Inward FDI stocks instead, to the extent that information is available. Finally, values in USD are adjusted by the average USD-EUR exchange rate in 2019.

We perform two further adjustments to the country-by-country data matrix. First, we apply the methodology proposed in Damgaard et al. (2019) to distinguish between real FDI and what is conduit FDI. We use FDI-to-GDP ratios and the authors' baseline regression-based prediction model to identify the share of real FDI in total FDI for each destination country. While most countries have shares at or close to 100%, a few countries, notably Luxembourg, Malta, Cyprus and Ireland, feature smaller shares of real FDI according to the estimations.

Second, we use a method developed by UNCTAD that allows for the estimation of a bilateral FDI matrix that provides stocks by ultimate counterparts by removing conduit FDI (Casella, 2019). Reconstructing the global

[4] We take the notional maximum hours worked to be 2500, which is well above the average hours worked in any country in the model. The value itself is selected for the purposes of calibrating sensible values for the labour supply.

FDI stocks by ultimate investors provides a more accurate and complete snapshot of international production than do standalone bilateral FDI statistics.

3.1.3 Tax Revenue Data (Other Than Corporate Income Tax)

CORTAX comprises all main taxes. The calibration of each tax rate is country-specific. In this sub-section, we focus on taxes on income, profits and capital gains of individuals ($RevTax_{Inc,ind}$), taxes on payroll and workforce ($RevTax_{pay}$; including social security contributions, *SSC*) as well as general taxes on goods and services, including excise ($RevTax_{GoodServ}$ and $RevTax_{Excise}$). This classification closely resembles the categorization of the OECD revenue statistics. The data is directly retrieved from Eurostat for all EU countries and from the OECD for all remaining countries.

Tax Rates on Labour and Consumption

Tax rates on labour income and consumption are taken directly from Eurostat's "Data on Taxation Trends" database, which provides information on implicit tax rates for all EU Member States. For non-EU countries, for which rates are not directly available from Eurostat, tax rates on labour and consumption, τ_l and τ_c, are computed based on the following tax revenue information:

$$\tau_{l,OECD} = 1000\left(\frac{RevTax_{Inc,ind}\omega_{wl} + SSC + RevTax_{pay}}{\omega_{wl}(GDP - IndTax_{tot})}\right)$$

$$where\ \omega_{wl} = \frac{VA_L\left(1 + \frac{SE}{EE}\right)}{(GDP - IndTax_{tot})}$$

The first component, $RevTax_{Inc,ind}\omega_{wl}$, describes tax revenue due to labour income, profits and capital gains taxes. It is computed by multiplying the share of value added related to labour (both of employees and self-employed) with respect to the GDP (net of indirect taxes) with the tax revenue on income, profits and capital gains of individuals. Social security contributions and payroll taxes are added in the numerator. The denominator is the value added due to employees and self-employed. $(GDP - IndTax_{tot})$ is the GDP at factor cost which is equal to the value added of labour and capital.

Concerning consumption taxes we compute the ratio of all taxes levied on purchases of goods and services, including excise, relative to the value of these goods, net of taxes. Relevant information is retrieved from national accounts data.

$$\tau_{c,OECD} = 1000\left(\frac{RevTax_{GoodServ} + RevTax_{Excise}}{C_{Private+Gov,NA} - (RevTax_{GoodServ} + RevTax_{Excise})}\right)$$

Tax on dividends, interests and capital gains

Information on tax rates on dividends, interests and capital gains are taken from the ZEW publication on effective tax rates (Spengel et al., 2020). The tax rates used are those referring to top-rate shareholders with qualified participation.

3.1.4 Corporate Income Tax Regime

Information on country-specific effective statutory CIT rates is retrieved from Spengel et al. (2020), comprising nominal CIT rates and, in some country cases, surcharges and local profit tax rates. CIT revenue data for EU countries is obtained from Eurostat's data on "Direct tax revenue over GDP", more specifically, taxes on the income or profits of corporations including holding gains as a share of GDP. For non-EU countries we use the OECD data from the tax revenue dataset for corporate tax revenues as a share of GDP.

In order to properly parametrise each country's CIT regime, we use the Devereux-Griffith methodology on forward looking effective tax rates in order to determine the net present value of tax allowances for each country for three types of assets: Industrial buildings, Intangibles and Machineries.

Information for each country on the asset-type specific tax depreciation schedule is obtained from Spengel et al. (2020). Concretely, for every country and every asset type, the data specifies whether the type of depreciation is Declining Balance (*DB*), Straight Line (*SL*) or a mix of the two (*Mix*), the first year depreciation (φ) and the total number of years over which the asset will be written-off.

Depending on the specific depreciation methodology that applies, the net present value of future allowances (A^*) is computed as follows ([5]).

$$A_{DB}^* = \frac{\varphi}{\varphi + \rho}$$

$$A_{SL}^* = \frac{\varphi}{\rho}\left(1 - \frac{1}{(1+\rho)^t}\right)$$

$$A_{Mix}^* = \left(\frac{\varphi}{\varphi + \rho}\right)\left(1 - \frac{(1-\varphi)^t}{(1+\rho)^t}\right) + \frac{\varphi_2}{\rho}\left(1 - \left(\frac{1}{(1+\rho)^{t_2}}\right)\right)\left(\frac{1}{(1+\rho)^t}\right)$$

Parameter ρ is the shareholder discount rate and it is equal to the nominal interest rate. It is computed based on the assumption of a long-run equilibrium inflation rate of 1.875% and a real interest rate of 3%; the parameter φ_2 stands for a potential second different rate of depreciation which is to be applied after t years, for an additional t_2 years in those cases where a Declining Balance principle is used for t years, followed by a Straight Line methodology for the next t_2 years.

Next, we compute, for each country and each sector, the share of tangible assets, comprising lands, buildings and machineries. This calibration is carried out based on data from Eurostat's Structural Business Statistics (SBS) data. More specifically, it contains information for every year at the country-sector level on gross investment in tangible goods ($Tangible$), gross investment in land ($Land$), gross investment in existing buildings and structures ($Build_{old}$), gross investment in construction and alteration of new buildings ($Build_{new}$) as well as gross investment in machinery and equipment ($Mach$). Thus, we compute for each country c and each sector s the shares of Land, Building and Machineries, respectively, at time t.

$$\%Land_{c,s,t} = \frac{Land_{c,s,t}}{Tangible_{c,s,t}}$$

$$\%Build_{c,s,t} = \frac{Build_{old,c,s,t} + Build_{new,c,s,t}}{Tangible_{c,s,t}}$$

$$\%Mach_{c,s,t} = \frac{Mach_{c,s,t}}{Tangible_{c,s,t}}$$

In order to obtain a long-run equilibrium share we use the average over three years between 2017 and 2019 with some slight re-adjustments so that they sum up to 100%.

As Eurostat does not include information on the United States and Japan, we use information from McKenzie (1998) to obtain the production input shares of land, machineries and buildings by sector, again slightly readjusting so that the sum is equal to 100%. Finally, we use a cross-walk from the McKenzie sector classification to NACE in order to have NACE-specific input shares.

While Eurostat and the data from McKenzie (1998) contain information at the sector-level on the share of machinery and buildings, these sources do not report any value for intangible assets, though. For this reason, we merge the dataset with firm-level information from Orbis *Bureau van Dijk* from 2019. For each firm i, the share of intangible assets is obtained as the ratio of intangible fixed assets over total fixed assed defined as the sum of tangible and intangible fixed assets, inventories and other fixed assets (i.e. financial assets).

$$Share_{int,i} = \frac{Int_i}{(Int_i + Tang_i + Stock_i + FinAss_i)}$$

As the share of building, machineries and land we previously computed in Eurostat were shares of tangible assets, we must now compute how much each of these assets account for considering that tangible asset is

[5] The A* represents the net present value of the future allowance and not of the tax saving coming from the allowance, thus is slightly different from the concept of A in Spengel et al. (2020). This difference is due to the way in which A is used in CORTAX, since it is then multiplied in the model by the country-specific CIT rate.

just one part of the assets owned by firms. Thus, we multiply the shares of machineries, land and building computed in Eurostat, by the share of tangible assets over all assets as follows:

$$Share_{Land,i,s} = Share_{Land,s} \frac{Tang_i}{(Int_i + Tang_i + Stock_i + FinAss_i)}$$

$$Share_{Build,i,s} = Share_{Build,s} \frac{Tang_i}{(Int_i + Tang_i + Stock_i + FinAss_i)}$$

$$Share_{Mach,i,s} = Share_{Mach,s} \frac{Tang_i}{(Int_i + Tang_i + Stock_i + FinAss_i)}$$

Finally, the net present value for future allowance can now be computed for every firm i in country c, in every year t by combining the information on the shares of assets with the net present value of the allowance for each of the assets:

$$A^*_{i,c} = A^*_{Build,c} Share_{Build,i} + A^*_{Mach,c} Share_{Mach,i} + A^*_{Int,c} Share_{Int,i}$$

In the same vein, we compute the first year depreciation as follows

$$\varphi^*_{i,c} = \varphi^*_{Build,c} Share_{Build,i} + \varphi^*_{Mach,c} Share_{Mach,i} + \varphi^*_{Int,c} Share_{Int,i}$$

As a final step, we compute the cross-firm averages of $A^*_{i,c}$ and $\varphi^*_{i,c}$ to obtain country-specific variables to be used within CORTAX.

In addition, the model uses the average debt share of firms in each country, which is defined as the ratio of the sum of liabilities of all firms in a country over the sum of total assets for all firms in the same country, and the probability to incur for the parameterisation of the loss carry-forward.

3.1.5 CIT-related Tax Compliance Costs

Firms' tax compliance costs in CORTAX are measured as a share of the labour force employed for dealing with tax administration. Overhead labour dedicated to tax compliance tasks is designed as a fixed fraction of the productive workers and effectively increases the wage cost by this fraction.

The calibration is based on a study on tax compliance costs by KPMG prepared for the Executive Agency for Small and Medium-sized Enterprises. Existing survey evidence covers all EU countries in 2019, sampled in strata according to enterprise size and NACE 1-digit industry. The survey reports data about the money-equivalent time spent internally on tax compliance for various tax categories as well as the monetary cost for outsourced compliance services. Average country-specific and firm-type-specific CIT-related compliance costs per firm are readily available from the report and the underlying micro-data. To convert the series into shares of labour costs, which is the way compliance costs are represented in the CORTAX model, we compute for each firm observation the total labour costs, given the number of employees of the firm (from the micro-data), average wages in the country and the average number of hours worked (from Eurostat). The calibration in CORTAX requires to distinguish between compliance costs of MNEs and domestic firms. While the information is not available from the micro-data, we classify large companies with more than 250 employees, which are labelled as either "Ultimate parent" or "Enterprise with subsidiaries" as MNEs. On the other hand side, we consider small firms, with less than 50 employees, and which are labelled as "Standalone" enterprises as domestic firms. Furthermore, a re-weighting of the survey sample adjusts according to relative proportions of firm numbers by country, size class and NACE industry.

According to our computations, corporate income tax related compliance costs in 2019 are on average, across all EU27 countries, approximately 2.6% and 1% of labour costs for domestic firms and MNEs, respectively, with some degree of cross-country heterogeneity.

3.1.6 Government Cost of Tax Collection

In CORTAX governments incur a cost for tax collection, which is country-specific. The OECD's Tax Administration data (Table D.3 Resource ratios, Annex tables) contains information on the recurrent cost of tax collection (the total operating expenditure as a share of net revenues collected) and the revenues collected as a share of GDP. The ratio of the two variables yields an estimate of the annual recurrent costs of total tax collection as a share of GDP, which is used for the calibration in CORTAX. In order to obtain CIT-related tax collection costs, which is the relevant parameter for CORTAX, we multiply the obtained costs-to-

GDP ratio with the average share of CIT revenues to total revenues, which was about 12% for the countries in CORTAX in 2019, assuming that tax-category-specific costs are proportional to their revenue share.

On average, across all CORTAX countries, the recurrent CIT-related tax collection costs amounts to approximately 0.05% relative to GDP in annual terms in 2019 with some country heterogeneity.

3.1.7 Corporate Taxation under Formulary Apportionment

CORTAX also allows corporate taxation under formulary apportionment, that is consolidated profits (and potentially losses) are reapportioned to tax jurisdictions according to a weighting rule, the so-called apportionment formula. Each country is assigned a share of the tax base that depends on the specific factors included in the formula. Apportionment factors that follow directly from the model simulation are (1) local payroll costs, (2) local output shares, (3) local employment shares, and (4) shares in local total capital stocks.

3.1.7.1 Tangible and Intangible Capital

The apportionment formula can also include the share of local intangible capital, approximated in various different forms.

(1) Intangible assets depending on the legal ownership, i.e. where the entity has them booked in its financial accounts. The location of intangible assets by country of ultimate parent entity is based on unconsolidated financial account data from Orbis Bureau van Dijk. A straightforward imputation method, based on a regression specification with a small set of basic accounting variables and country-pairs as well as industry-specific averages as predictors, addresses issues of data non-reporting (i.e. many firms report only aggregate total assets, without further disaggregation in tangible and intangible assets).

(2) Allocation of R&D costs: allocation of R&D-related costs by location of where those costs are incurred is based on the EU *Industrial R&D Investment Scoreboard*. The micro-dataset comprises 2,500 companies investing the largest sums in R&D in the world in 2018/19. These companies, based in 44 different Headquarter (HQ)-countries, each invested over EUR 30 million in R&D for a total of more than EUR 820bn, which is approximately 90% of the world's business-funded R&D. The data also contains information on location of critical researchers. Drawing from local average wages for research staff (from Eurostat), this allows to compute local wage costs, which we assume to be proportional to overall R&D-related costs in a country of subsidiary. Finally, R&D-related expenditures are allocated according to the local share of labour costs.

(3) Location of critical staff for performing R&D activities: In a similar vein as for Option (2), in this case we apportion consolidated R&D costs according to the number (headcount) of locally employed researchers instead of wage costs.

3.1.7.2 Sales by Destination Country

Sales by destination country is calibrated by starting from local production levels and adjusting those figures by the net-export share of each destination country (taken from World Bank data).

3.1.8 Corporate tax revenue to GDP

As already noted, the corporate tax base is elaborated in detail in CORTAX. Multiplied by the rate applied gives the CIT revenue (once adjustments for profit shifting are accounted for). Nevertheless, it is not possible to incorporate all the details in the actual tax systems. For example, some countries make exceptions for certain industries or activities, such as research and development (R&D). On average, the unadjusted CIT revenue-to-GDP ratio is about 9% smaller than the actual CIT revenue-to-GDP ratio. Therefore, to match precisely the data values for CIT revenue as a share of GDP, we add a balancing factor. This can be thought of as capturing idiosyncrasies of the tax system, not explicitly modelled in the CORTAX equations.

3.2 Parameters

CORTAX requires values for a large number of parameters, which are split here into those for model equations, long-run data estimates, production, and profit shifting. In all cases the description and CORTAX name of each parameter can be found in Bettendorf et al. (2006), where the equation(s) in which it features is described.

3.2.1 Model Equation Parameters

The model equation parameters are selected according to the standard values found in the literature. They range from parameters specifying the intertemporal substitution elasticities to the time preference to the substitution elasticity between bonds and equity. The share of domestic corporate profits taxed as corporate profits is equal to one in the base model, implying that this is the treatment for all domestic corporate profits. The weighting factor for EATR, which is one in the base model, implies that all of the weighting goes on the effective average tax rate, rather than the effective marginal tax rate. Both these factors can be adjusted in simulations, if desired. The cohort length is 40 years, referring to the two periods of life modelled: young (age 20-59) and old (age 60-99), which forms part of the household lifetime optimisation choice.

Table 1. Model equation parameters.

Description	**CORTAX Name**	**2019**
intertemporal substitution elasticity 1	σ_l	1
intertemporal substitution elasticity 2	σ_u	0.5
time preference	ρ_u	1.01
taste for bonds in savings	α_s	0.7
substitution elasticity bonds-equity	σ_s	4
multiplier in debt cost equation	χ_0	0.015
elasticity of marginal cost of transfer pricing	ε_q	1
Parameter used for endogenous interest rate, bonds	$\gamma_{0,b}$	0.01
Parameter used for endogenous interest rate, equity	$\gamma_{0,e}$	0.01
share of domestic corporate profits taxed as corporate profits (vs labour income)	$share_p$	1
Weighting factor for the computation of the EATR	α_{EATR}	1
cohort length (length of young/old period in years; age 20-59/60-99)	T	40

Source: CORTAX 2019.

3.2.2 Long-Run Data Estimates

The values selected seek to reflect the long run values, and may not reflect the base year. Necessarily, there is a certain amount of judgement involved. Note also that growth rates are identical for all countries in order to avoid an explosive long run solution.

Table 2. Parameters: long-run data estimates.

Description	CORTAX Name	2019
world rate of return on bonds	rw_b	0.015
world rate of return on equity	rw_e	0.03
technological growth	g_a	0.015
inflation rate	g_p	0.01875
GDP growth rate (steady state)	g_y	0.0227

Source: CORTAX 2019.

3.2.3 Production Parameters

The following parameters relate to creating the production structure. The fixed factor in production is a notional device that ensures that some production is derived from a country-specific immovable production factor, such as land. (It also ensures that some positive corporate tax is optimal.) It is assumed that the use of this factor is skewed towards domestic firms, more than MNEs. It is also assumed that share of the fixed factor is 2.5% in the production function, hence the share of value added in production is 0.975. Intermediate inputs is introduced into the model to capture transfer pricing between countries. The share of intermediate inputs in the production process of subsidiaries of MNEs, next to labour, capital and the fixed factor, is assumed to be 10%.

The probability of making positive profits, as opposed to a loss, is estimated from the data. The substitution elasticity between labour and capital is selected to be less than one (0.7).

Table 3. Production parameters.

Description	CORTAX Name	2019
share of domestic firms in fixed factor	ω_d	0.7
share of multinationals in fixed factor, MNE-HQ	ω_m	0.3
share of value added in production, domestic firms,	$\alpha_{v,d}$	0.975
share of value added in production, MNE-HQs	$\alpha_{v,m}$	0.975
share of intermediate inputs in production, MNE subsidiaries	α_q	0.1
probability of making non negative profits, domestic firms	q_{fd}	0.78
probability of making non negative profits, MNEs	q_f	0.78
substitution elasticity labour-capital	σ_v	0.7

Source: CORTAX 2019.

3.2.4 Profit Shifting Parameters

The following parameters relate specifically to profit shifting to tax havens. The tax rate in the notional tax haven is selected to be 5%, chosen to be between the merely low rates of certain countries that are used as tax havens and the extremely low rates found in other tax havens. Given this rate in the notional tax haven, the elasticity values are selected to match estimates of profit-shifting elasticity. Details are provided in Álvarez-Martínez et al. (2020).

Table 4. Profit shifting parameters.

Description	**CORTAX Name**	**2019**
tax rate in tax haven	τ_{ph}	0.05
elasticity of profit shifting to tax haven	γ_{sh}	0.9
tax-elasticity of profit shifting to tax haven (domestic firms)	$\pi_{sh,d0}$	0.206
tax-elasticity of profit shifting to tax haven (MNEs)	π_{sh0}	0.648

Source: CORTAX 2019.

4 Baseline Characteristics of the 2019 Calibration

The calibration and structure of CORTAX determine how the model responds to policy reforms or any exogenous shock. To help explain this response, we calculate and explain here some key statistics that emerge from the model (6).

4.1 Financial Distortions

In CORTAX, the cost of financial distress is a key determinant of the impact of corporate tax on the firms' financial behaviour in terms of debt or equity financing. In general, all countries feature a positive semi-elasticity of the debt share with respect to the corporate income tax rate. Thus, an increase in the CIT rate leads to an increase in firms' debt share as debt interest payments are deductible from the CIT base. However, the cost of financial distress is a convex function, which causes the semi-elasticity to fall with the corporate tax rate. This is demonstrated in **Figure 1**, which shows the semi-elasticities of the debt share with respect to the corporate tax rate for all countries with the prevailing corporate tax rate in each.

Figure 1. Semi-elasticity of the debt share w.r.t. the corporate tax rate.

Source: Own calculations using CORTAX 2019 (7).

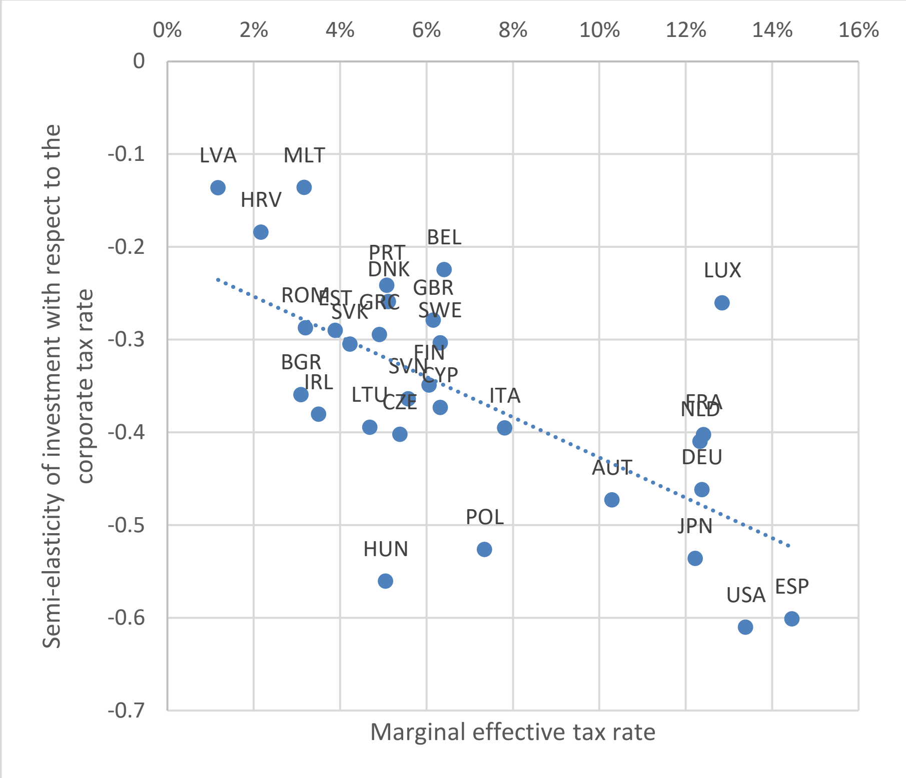
4.2 Investment Distortions

Corporate tax clearly impacts on investment decisions in CORTAX. The channel of transmission is that corporate tax changes the cost of capital, which in turn, changes the optimal level of investment. **Figure 2Error! Reference source not found.** reports the semi-elasticity of investment with respect to the corporate tax rate, which ranges for the countries under consideration from -0.14 down to -0.61. The differences can be largely understood by noting the differences in the baseline marginal effective tax rate (METR): high METRs lead to a larger (more negative) semi-elasticities, as can be seen in the figure.

6 Further discussion about how CORTAX elasticities relate to the wider literature can be found in Bettendorf et al. (2009).

7 The semi-elasticities in this section are produced within the model by introducing a marginal increase in the corporate tax rate and re-solving the model to find the new equilibrium values for the debt share (**Figure 1**), investment (**Figure 2**), the transfer price (**Figure 3**), and the tax base (**Figure 4**). Comparing these with the base values allows the elasticities to be inferred directly.

Figure 2. Semi-elasticity of investment w.r.t. the corporate tax rate.

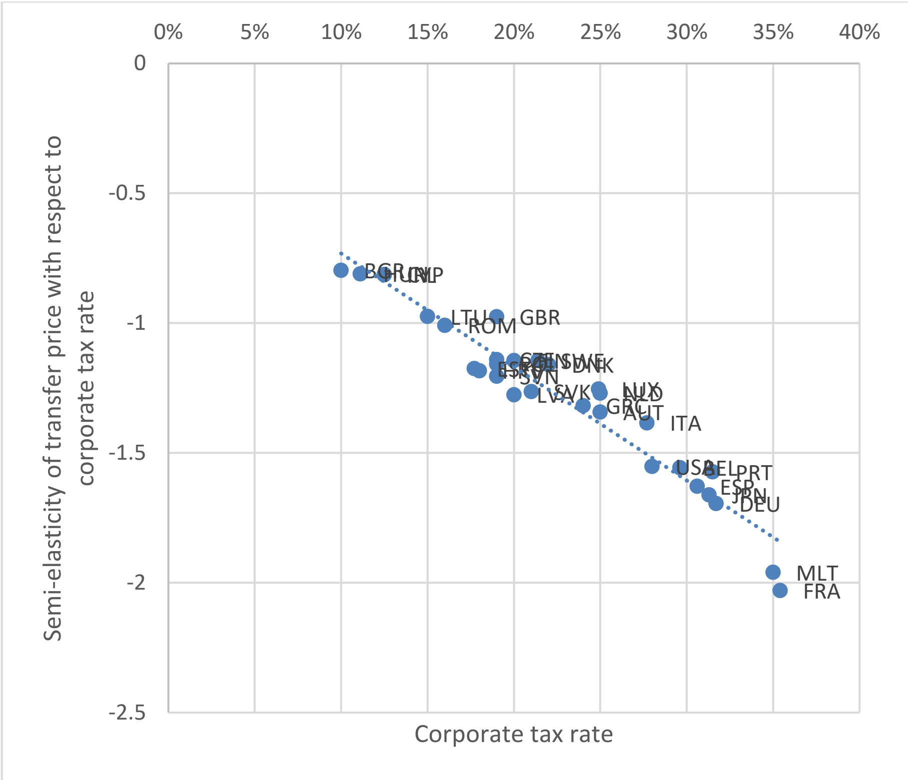


Source: Own calculations using CORTAX 2019. (See footnote 7 for details.)

4.3 Transfer Pricing Distortions

Transfer pricing in CORTAX incurs convex costs, which increase as more transfer pricing is undertaken. As a result of the shape of this function, countries with corporate tax rates in the base adjust the amount of transfer pricing more with corporate tax rates changes. This relationship is shown in **Figure 3**.

Figure 3. Semi-elasticity of investment w.r.t. the corporate tax rate.

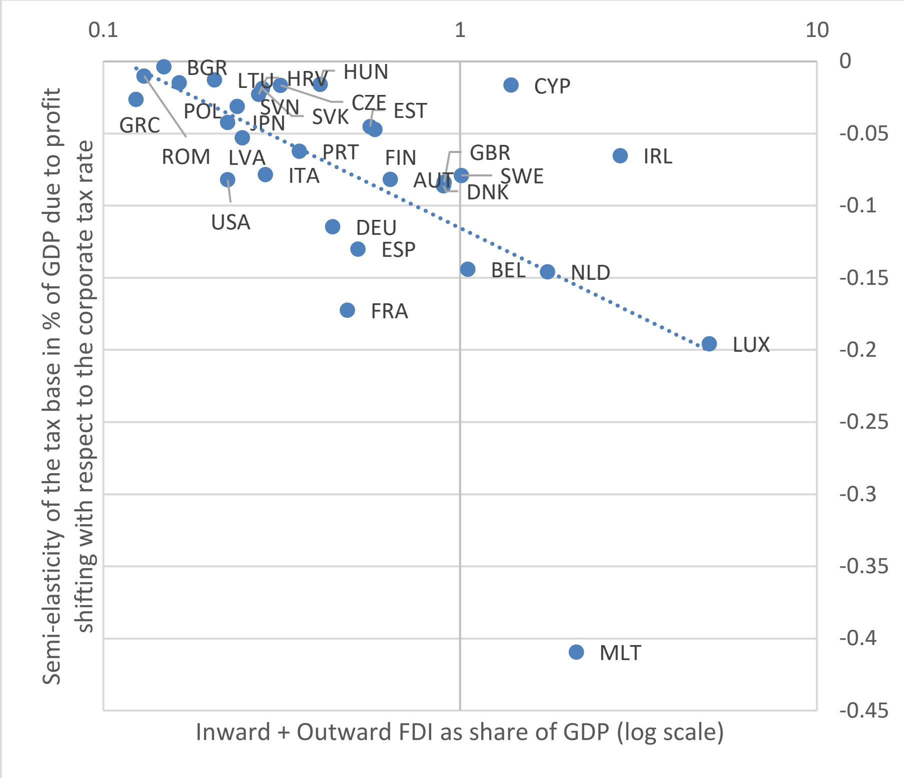


Source: Own calculations using CORTAX 2019. (See footnote 7 for details.)

4.4 Profit shifting to tax havens

A proportion of the corporate tax that would be collected is shifted to a notional tax haven in CORTAX. The amount of profit shifting is determined by the convexity of the cost of profit shifting function (the values are explained in the Parameters section 3.2 above). The semi-elasticity of the corporate tax base with respect to the corporate tax rate is shown on the vertical axis in **Figure 4**. Countries with low statutory tax rates, such as Hungary or Bulgaria, face very low elasticities, whilst those with higher statutory tax rates, such as France or Malta, face higher elasticities. An important determinant is that countries with more FDI stocks (inward or outward) will feature larger elasticities of profit shifting, as shown in the figure. (Note that the horizontal axis is on a log scale for readability, because most countries bunch as a share of GDP between 0.1 and 1.)

Figure 4. Semi-elasticity of tax base due to profit shifting w.r.t. the corporate tax rate.



Source: Own calculations using CORTAX 2019. (See footnote 7 for details.)

5 Conclusions and outlook

CORTAX continues to be a valuable tool to analyse the macroeconomic impacts of corporate tax reforms. Indeed, few such tools have been developed and maintained ([8]). CORTAX has been particularly useful in the context of ex-ante analysis of a variety EU-wide reforms, demonstrating a capacity to capture the salient features and how they impact the macroeconomic environment.

As the model that is being actively used for policy work, model developments respond to demands from policy-makers. Depending on the policy area, additional data or equations can sometimes be added to address a particular issue, drawing upon the wider corporate tax research as appropriate.

An ongoing challenge is to maintain the model as up-to-date as possible, given the high data requirements. Across the countries modelled in CORTAX (the EU27 Member States, the USA, the UK and Japan), some changes in the corporate tax rates occur fairly frequently, as do some of the rules for calculating the tax base. We are looking to automate this process to the extent possible to allow for new calibrations to be produced in the most timely manner possible.

An interesting avenue for development would be to extend CORTAX to include multiple sectors. Indeed, some previous work has already simulated a two-sector version of CORTAX, which split out the digital economy into its own sector. This could be accomplished by combining the current model structure with some elements of a more traditional computable general equilibrium (CGE) structure. The advantage of this would be to analyse corporate tax reforms that were targeted at particular categories of production.

[8] Ferrari et al. (2022) is a notable exception. Despite being similar in nature, their general equilibrium model is tailored towards modelling the extent and directions of firms' profit shifting but is more limited in terms of scope for policy options. For example, it does not allow to model the impact of a change to a system of formulary apportionment, nor adjustments to the relative attractiveness of debt and equity financing of firms, both of which have taken centre stage in recent CIT reform proposals.

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List of abbreviations and definitions

AMECO	Annual Macro-Economic database of the European COmmission
CDIS	Coordinated Direct Investment Survey (IMF)
CES	Constant Elasticity of Substitution
CIT	Corporate Income Tax
DEBRA	Debt-Equity Bias Reduction Allowance
FDI	Foreign Direct Investment
METR	Marginal Effective Tax Rate
MNE	Multi-national Enterprise
R&D	Research and Development
NACE	Nomenclature statistique des Activités économiques dans la Communauté Européenne (The Statistical classification of economic activities in the European Community)
UNCTAD	United Nations Conference on Trade and Development

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