The Economic Research Center Tax Model Methodology for Ohio

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Economists at The Buckeye Institute's Economic Research Center (ERC) have developed and maintain a dynamic scoring model to analyze how changes to tax policy impact not only government revenues but also economic output, job creation, and business investment. Unlike static models that do not account for human or market responses to policy changes, the ERC's dynamic model predicts how individuals, households, and businesses will alter their economic choices in response to changes in the private economy and public policy over time.

The ERC calibrated the model for Ohio using publicly available state and federal data, and relied on a similar dynamic scoring framework used by federal agencies to evaluate federal tax proposals to predict how certain policy changes will affect gross domestic product (GDP), job creation or loss, and government revenue.

The ERC's model has undergone a double-blind peer review and incorporated comments from those reviews consistent with current academic standards and methodologies. The model's full technical description provided below will allow researchers to validate the model's accuracy and the conclusions that we draw in our research.

The Model Framework

The ERC's dynamic model provides a framework representing a generic state economy, with its parameters calibrated to the specific state being analyzed. It allows researchers to study the interaction of households' economic choices and firms' profit maximizing decisions with a state government that pays for its budget by taxing households and businesses. The model framework is similar to those used to study national policy, modified with some conditions tailored to the specific economic conditions of a state. Because states have more limits to trade and debt relative to a national economy, for example, the ERC's model includes a condition in which state governments satisfy a budget constraint where debt cannot increase beyond a certain level. Our model is comprised of the following three parts:

1) *The Household Problem*: Households choose how much to consume and how much to work based on their preferences and their budgets. Households can also choose to take on debt or invest in capital used by firms. Their budgets factor in sales and excise taxes on consumption, labor income (both at the state and federal level), capital income (both at the state and federal level), and licensing. The parameters governing these taxes are estimated using state and federal data.

2) *The Firm Problem*: Firms choose labor and capital, supplied by the household, to maximize profits taking the costs of production (wages, the price of capital, and taxes) as given. Using state-level data, the model simulates production within separate sectors. The output produced is used for consumption, government expenditures, or investments in factors of production.

3) *The Government Sector*: The government sets taxes to collect revenue to pay for its expenditures; however, deficits and surpluses are allowed to a limited degree. The state's trade balance is a mathematical output of what is consumed, invested in, and government expenditures less total production in the economy.

With this framework, we then explicitly define how households and firms make their economic choices.

In the model environment, time is discrete and lasts forever. In every period the economy is populated by heterogeneous households specialized in the production of one of s types of goods. The Bureau of Economic Analysis (BEA) reports macroeconomic data for the 50 states in yearly intervals, so each period represents a year in this framework. Each sector s is populated by a large number of firms specialized in the production in their sector. The economy also features a government sector that collects taxes and purchases goods from all sectors. A share $q^e \in (0,1)$ of households has earning ability $e = \{1, \dots, E\}$. These shares are such that the total population is $\sum_{e=1}^{E} q^e = 1$. The share of households with the required skills to work in sector s is $\mu_s \in (0,1)$ such that $\sum_{s=1}^{S} \mu_s = 1$. We then outline each part of the model: the household problem, the firm problem, and the government sector.

The Household Problem

The household has preferences between consumption and leisure. These preferences are represented by a period t utility function U_t, which takes the following form:

$$U_t = \sum_{s=1}^{S} \alpha_s \ln\left(c_{e,t}(s)\right) - \chi_e l_{e,t}(s)^{\left(1+\frac{1}{\psi_e}\right)}$$

Taking the prices, taxes, and previous period $t-1$ choices as given, each period t, household e chooses: how much to consume $c_{e,t}(s)$ from each sector s; the amount of future capital stock $k_{e,t}(s)$ for each sector s; investment $x_{e,t}(s)$ for each sector s; how much to borrow in debt $d_{e,t}$; and how much to work $l_{e,t}(s)$ in each sector s. Households place a utility weight on consumption goods according to $\alpha_s \in (0,1)$ where α_s represents the share of total GDP in sector s. Period time is split between labor and leisure such that total time is normalized to 1. Leisure $h_{e,t}$ can be defined as:

$$h_{e,t} = 1 - \sum_{s=1}^{S} l_{e,t}(s)$$

where $h_{e,t} \in [0,1]$ and $l_{e,t}(s) \in [0,1]$. The parameter that regulates the Frisch elasticity of labor supply is denoted ψ_e. χ_e is a scaling factor that helps match hours worked observed in the data. The household seeks to maximize its utility by solving the following problem:

$$V_{e,t}(s) = \max_{c_{e,t}(s), x_{e,t}(s), l_{e,t}(s), k_{e,t}(s), d_{e,t}} U\left(c_{e,t}\right) - \chi_e l_{e,t}(s)^{\left(1+\frac{1}{\psi_e}\right)} + \beta E[V_{e,t+1}(s)]$$

The economic decisions for period t are subject to the following constraints:

$$\begin{aligned} d_{e,t} = {} & (1 + \tau_t^c + \tau_t^{ex}) \sum_{s=1}^{S} c_{e,t}(s) + \sum_{s=1}^{S} x_{e,t}(s) + \left(1 + i_{r,t-1}\right) d_{e,t-1} + \tau_t^k \sum_{s=1}^{S} k_{e,t-1}(s) \\ & + \left[\frac{\phi}{2}\left(\sum_{s=1}^{S} k_{e,t}(s) - \sum_{s=1}^{S} k_{e,t-1}(s)\right)^2\right] - \ (1 - (1 - \eta_{e,t}^{i,n}) \tau_{e,t}^{i,n} - \tau_t^o \\ & - \tau_{e,t}^{i,n,f}) \sum_{s=1}^{S} w_{e,t}(s) l_{e,t}(s) - (1 - (1 - \eta_{e,t}^{i,r}) \tau_{e,t}^{i,r} - \tau_t^o - \tau_{e,t}^{i,r,f} \\ & - \tau_t^{corp}) \sum_{s=1}^{S} r_{e,t}(s) k_{e,t-1}(s) \end{aligned}$$

$$k_{e,t}(s) = x_{e,t}(s) + (1 - \delta) k_{e,t-1}(s)$$

$$c_{e,t}(s) \geq 0$$

$$k_{e,t}(s) \geq 0,\ k_{e,T+1}(s) = 0$$

$V_{e,t}(s)$ defines expected utility discounted at a patient factor $\beta \in [0,1]$. As in Mendoza (1991), ϕ denotes a capital adjustment cost. The return on capital lent to firms is $r_{e,t}(s)$. The wage paid to workers of type e in sector s is $w_{e,t}(s)$. Future capital stock $k_{e,t}(s)$ is the sum of current capital stock $k_{e,t-1}(s)$, accounting for depreciation δ, and investment $x_{e,t}(s)$. $i_{r,t}$ denotes the interest rate at which domestic residents can borrow from international markets in period t, and $d_{e,t}$ is household debt.

Following Schmitt-Grohé and Uribe (2003), we assume a debt elastic interest rate. This is modeled as $i_{r,t} = i_{r,w} + \zeta(e^{D_t - D} - 1)$ where $i_{r,w}$ is the world interest rate faced by domestic agents and is assumed to be constant and ζ and D are constant parameters that are calibrated to match the state's economy. $\zeta(e^{D_t - D} - 1)$ is the state specific interest rate premium that increases with the level of debt. D_t represents the aggregate state level of debt, such that $D_t = \sum_{e=1}^{E} d_{e,t}$.

τ_t^c is the tax on household consumption purchases, which includes general sales tax, and τ_t^{ex} is the excise tax rate. $\tau_{e,t}^{i,n}$ is the statutory individual labor income tax rate, and $\tau_{e,t}^{i,r}$ is the individual capital income tax rate. $\eta_{e,t}^{i,n}$ and $\eta_{e,t}^{i,r}$ are the proportions of labor income and capital income respectively that are deducted or otherwise exempt from income taxes. $\tau_{e,t}^{i,n,f}$ is the individual labor income tax collected by the federal government, and $\tau_{e,t}^{i,r,f}$ is the individual capital income tax collected by the federal government. Income tax rates depend on the individual earning ability e. τ_t^k is a tax on fixed assets owned by households. τ_t^{corp} is the corporate income tax faced by the owners of capital. τ_t^o is the share of income paid to all other taxes, fees, and revenue sources for the state government not included specifically in the model.

The variables representing households' economic decisions for each period t and sector s can be summarized as the set: $\left\{\{c_{e,t}(s), x_{e,t}(s), l_{e,t}(s), k_{e,t+1}(s)\}_{s=1}^{S}, d_{e,t}\right\}_{t=0}^{\infty}$. The household then maximizes the utility function subject to the resource constraint and a no-Ponzi scheme constraint that implies that the household's debt position must be expected to grow at a rate lower than the interest rate in the long-run.

The Firm Problem

In each sector s, a large number of competitive firms produce goods according to the following constant elasticity of substitution (CES) production function:

$$y_t(s) = a_t\left(\sum_{e=1}^{E}\left((\theta_s)\left(k_{e,t-1}(s)\right)^{-\rho} + (1-\theta_s)\left(z_e\, l_{e,t}(s)\right)^{-\rho}\right)^{-\frac{1}{\rho}}\right)$$

where $\boldsymbol{a_t}$ is total factor productivity (TFP), θ_s is associated with the capital share of total output in sector s, and $\sigma_{CES} = \frac{1}{1-\rho}$ is the constant elasticity of substitution between capital and labor. z_e is labor productivity specific to a household member's earning ability. These firms solve the following profit maximization problem:

$$\Pi_t = (1-\tau_t^{CAT})a_t\left(\sum_{e=1}^{E}\left((\theta_s)\left(k_{e,t-1}(s)\right)^{-\rho} + (1-\theta_s)\left(z_e\, l_{e,t}(s)\right)^{-\rho}\right)^{-\frac{1}{\rho}}\right) - \sum_{e=1}^{E} w_{e,t}(s) l_{e,t}(s) - \sum_{e=1}^{E} r_{e,t}(s) k_{t-1}(s)$$

It is important to note that the demand for labor and capital is sector s specific. τ_t^{CAT} is a commercial activity tax, modeled as a tax on a firm's revenues.

The representative firm in sector s hires labor according to the following condition:

$$(1-\tau_t^{CAT})\,(1-\theta_s)a_t\left((\theta_s)\left(k_{e,t-1}(s)\right)^{-\rho} + (1-\theta_s)\left(z_e\, l_{e,t}(s)\right)^{-\rho}\right)^{-\frac{1}{\rho}-1}\left(z_e l_{e,t}(s)\right)^{-\rho-1} z_e = w_{e,t}(s),$$

where $w_{e.t}(s)$ is the wage rate for type e in sector s. The demand for capital is such that:

$$(1-\tau_t^{CAT})(\theta_s)a_t\left((\theta_s)\left(k_{e,t-1}(s)\right)^{-\rho} + (1-\theta_s)\left(z_e\, l_{e,t}(s)\right)^{-\rho}\right)^{-\frac{1}{\rho}-1}\left(k_{e,t-1}(s)\right)^{-\rho-1} = r_{e,t}(s),$$

We assume a_t follows a stationary mean zero autoregressive process of order 1 in the log, which can be represented in the following way:

$$(a_t) = \rho_A(a_{t-1}) + \epsilon_{A,t}$$

The innovation shock $\epsilon_{A,t}$ is drawn from a standard normal distribution.

The Government Sector

The government sets taxes and collects revenue to make purchases. Its contribution to the rainy day fund RF_t is the excess of tax revenue plus federal government transfers net of government spending added to the previous period's balance.

$$RF_t = TR_t + FF_t - g_t + \left(1 + i_{r,t}\right)RF_{t-1}$$

Deficits—negative contributions—to the rainy day fund reduce the fund's balance.

The state government's tax revenues TR_t are given by:

$$TR_t = \sum_{s=1}^{S}\left(\sum_{e=1}^{E}\Big(\mathrm{\tau_t^{CAT}} y_{(e,t)}(s) + (\tau_t^c + \tau_t^{ex})c_{e,t}(s) + (1 - \eta_{e,t}^{i,n})\tau_{e,t}^{i,n}\, w_{e,t}(s)l_{e,t}(s) \right.$$
$$\left. + (1 - \eta_{e,t}^{i,r})\tau_{e,t}^{i,r}\, r_{e,t}(s)k_{e,t-1}(s) + \tau_t^k k_{e,t-1}(s)\Big) + \tau_t^o\, y_t(s)\right)$$

Government spending is proportional to GDP and is specified as $g_t = \hat{g}_t y_t$. This implies that government spending is assumed to grow as the economy grows. Spending policy $\hat{g}_t$ is assumed to evolve according to:

$$\hat{g}_t = \left(1 - \rho_{g,h}\right)(\hat{g}) + \rho_{g,h}(\hat{g}_{t-1}) + \epsilon_g$$

where $\hat{g}$ is the state share of income spent by the government sector in the long-run, the steady-state equilibrium. Variables without the time subscript denote steady-state values.

The tax instruments follow the exogenous processes:

$$\tau_t^{i,n} = (1 - \rho_{i,n})\tau^{i,n} + \rho_{i,n}\tau_{t-1}^{i,n} + \epsilon_{i,n}$$
$$\tau_t^{i,r} = (1 - \rho_{i,r})\tau^{i,r} + \rho_{i,r}\tau_{t-1}^{i,r} + \epsilon_{i,r}$$
$$\tau_t^c = (1 - \rho_c)\tau^c + \rho_c\tau_{t-1}^c + \epsilon_c$$
$$\tau_t^{ex} = (1 - \rho_{ex})\tau^{ex} + \rho_{ex}\tau_{t-1}^{ex} + \epsilon_{ex}$$
$$\tau_t^{corp} = (1 - \rho_{corp})\tau^{corp} + \rho_{corp}\tau_{t-1}^{corp} + \epsilon_{corp}$$
$$\tau_t^k = (1 - \rho_k)\tau^k + \rho_k\tau_{t-1}^k + \epsilon_k$$

$$\tau_t^o = (1-\rho_o)\tau^o + \rho_o \tau_{t-1}^o + \epsilon_o$$
$$\tau_t^{i,n,f} = (1-\rho_{i,n,f})\tau^{i,n,f} + \rho_{i,n,f}\tau_{t-1}^{i,n,f} + \epsilon_{i,n,f}$$
$$\tau_t^{i,r,f} = (1-\rho_{i,r,f})\tau^{i,r,f} + \rho_{i,r,f}\tau_{t-1}^{i,r,f} + \epsilon_{i,r,f}$$
$$\eta_t^{i,n} = (1-\rho_{\eta,n})\eta^{i,n} + \rho_{\eta,n}\tau_{t-1}^{i,n} + \epsilon_{\eta,n}$$
$$\eta_t^{i,r} = (1-\rho_{\eta,r})\eta^{i,r} + \rho_{\eta,r}\eta_{t-1}^{i,r} + \epsilon_{\eta,r}$$

As in Schmitt-Grohé and Uribe (2003), we write the trade balance to GDP ratio (TB) in steady-state as:

$$TB = 1 - \frac{[c + x + g]}{y}$$

The Competitive Equilibrium

A competitive equilibrium is such that given the set of exogenous processes, households solve the household utility maximization problem, firms solve the profit maximization problem, and the capital and labor markets clear.

The Deterministic Steady-State

The characterization of the deterministic steady state is of interest for two reasons. First, the steady-state facilitates the calibration of the model. This is because the deterministic steady-state coincides with the average position of the model economy to a first approximation. Because of this, matching average values of endogenous variables to their observed counterparts (e.g., matching predicted and observed average values of the labor share, the consumption shares, or the trade-balance-to-output ratio) can reveal information about structural parameters that can be used in the calibration of the model. Second, the deterministic steady-state is often used as a convenient point around which to approximate equilibrium conditions of the stochastic economy (see Schmitt-Grohe and Uribe, 2003). For any variable, we denote its steady-state value by removing the time subscript.

Using the solution from the households' and firms' choice problems, the steady-state implies that:

$$1 = \beta\left[\left(1 - (1-\eta_e^{i,r})\tau_e^{i,r} - \tau^o - \tau_e^{i,r,f} - \tau^{corp}\right) r_e(s) + 1 - \delta - \tau^k\right]$$
$$y(s) = a\left(\sum_{e=1}^{E}\left((\theta_s)\left(k_e(s)\right)^{-\rho} + (1-\theta_s)\left(z_e\, l_e(s)\right)^{-\rho}\right)^{-\frac{1}{\rho}}\right)$$
$$(1-\tau^{CAT})a\left[\theta_s\left(\frac{k_e(s)}{l_e(s)}\right)^{-\rho} + (1-\theta_s)z_e^{-\rho}\right]^{-\frac{1}{\rho}-1}\theta_s\left(\frac{k_e(s)}{l_e(s)}\right)^{-\rho-1} = r_e(s)$$

These expressions deliver the steady-state capital-labor ratio, which we denote $\omega_e(s)$

$$\omega_e(s) \equiv \frac{k_e(s)}{l_e(s)} = (1-\theta_s)^{-\frac{1}{\rho}}(z_e)\left(\frac{\beta^{-1} - 1 + \delta + \tau^k}{a(1-\tau^{CAT})\theta_s\left(1-(1-\eta_{e,t}^{i,r})\tau_e^{i,r} - \tau^o - \tau_e^{i,r,f} - \tau^{corp}\right)} - \theta_s\right)^{\frac{1}{\rho}}$$

The steady-state level of capital is:

$$k_e(s) = \omega_e(s) l_e(s)$$

Finally, the steady-state level of consumption can be obtained by evaluating the resource constraint at the steady-state:

$$\sum_{e=1}^{E} c_e(s) = y(s) - \delta \sum_{e=1}^{E} k_e(s) - g\mu_s - TBy(s)$$

which implies: $y = c + x + g + TBy$

As for the parameter that dictates households' preference for leisure:

$$\chi_e = \frac{\alpha_s}{(1+\tau^c+\tau^{ex})c_e(s)} \times \frac{(1-(1-\eta_{e,t}^{i,n})\tau_e^{i,n} - \tau^o - \tau_e^{i,n,f})w_e(s)}{\left(1+\frac{1}{\psi_e}\right) l_e(s)^{\frac{1}{\sigma_e}}}$$

Data and Calibration

Our data for calibrating the model come from publicly available federal and state data sources. First, we present our sources for the model's output variables. Then we present the sources for the model parameters and our empirical methodology for calibrating the model.

Output Variables

Primarily, we utilize BEA Regional Economic Accounts for Ohio for our output. All GDP variables are reported in real (2012 dollars) per capita terms using the U.S. GDP deflator reported by the BEA and, if not declared otherwise, we refer to the period of 1963-2017.

Our GDP projections use the latest GDP values and apply the state's GDP long-run annual growth rate of 1.92 percent from 1992-2017.

For our measure of consumption, consumption expenditures on durable goods are subtracted from total personal consumption expenditures (PCE). We consider durable goods as investment goods, as is standard in the macroeconomics literature. The values for PCE are not available on the state-level prior to 1997.

We therefore use the long-run average share of consumption in GDP to obtain the level of consumption for each year from 1963-1997. Because the BEA does not report private fixed investment at the state level, we use the U.S. share of non-residential investment in GDP from the BEA, and multiply it by the state GDP to estimate non-residential gross investment. The sum of non-residential investment and consumption expenditures on durable goods represents our measure of investment. Our methodology excludes residential investment from our measure of investment (residential investment is excluded from GDP as well).

We base our employment data for the number of non-farm jobs on data from the Bureau of Labor Statistics. We calculate the employment shares per sector using data from the BEA Regional Economic Accounts. We took the average weekly hours worked from the Annual Social and Economic Supplement of the Current Population Survey. The average weekly hours worked at all jobs is divided by the total number of hours per week (168 hours) to calculate average labor supply used for the model calibration. For the baseline projections, employment is assumed to grow at its annual growth rate for 1992-2017 of 0.3 percent.

We used the following methodology to estimate the effects of the tax policy scenarios on employment because the model measures employment in hours worked (intensive margin). First, we use employment multiplied by the average hours worked per year (2,155 hours). This total number of hours worked per year is multiplied by the effect of the corresponding scenario in order to obtain the change in total hours worked for each scenario. Finally, the change in hours is converted into the number of full-time equivalent jobs gained or lost by dividing it by 2,080, which is the number of hours worked by a full-time equivalent employee according to the CBO's definition (Harris and Mok, 2015).

Model Parameters and Calibration

Typically, a calibration assigns values to the model parameters by matching first and second moments of the data that the model aims to explain. We utilize moments in state and federal data to estimate the model parameters.

Because depreciation data are not reported at the state level by the BEA, we refer to data for the U.S. economy. The sum of current cost depreciation in nonresidential private fixed assets and consumer durable goods is divided by the sum of current cost net stock of nonresidential private fixed assets and consumer durable goods for the years 1963-2015. The average over this period represents the depreciation rate in our model. The depreciation rate of capital is $\delta = 0.1$.

The world interest rate is $i_{r,w} = 0.04$, based on the difference between the nominal interest rate for three-month treasury bill and the GDP deflator.

To compute the sector-specific labor shares, we use data from the BEA Regional Income Division. Similar to Gomme and Rupert (2004), we divide the compensation of employees by the personal income for each sector. As personal income is not available for sectors, we construct it by multiplying the earnings per sector by the total economy's personal income-to-earnings ratio, which is from the BEA Regional Income Division. The capital share is simply one minus the labor share. The values refer to the years 1998-2017. The sector specific parameter θ_s is set to match the observed average labor shares for each of the $S = 9$ production sectors.[1] In the present model, the

[1] See complete list of sectors in the Tax Model Parameters section.

labor share is given by the ratio of labor income to output which is $1 - \theta_s$ at all times. To ensure that capital and investment are not being overstated (or understated), the parameter ν, a cost on holding capital, is applied to adjust the steady state rental rate of capital, calibrating it to match the state's investment share of GDP.[2]

The earning ability for household types is based on the distribution of income and population as reported in the Ohio Department of Taxation annual report for Fiscal Year 2018.[3]

- Earning ability 1 has an adjusted gross income (AGI) of up to $50,000 per year;
- Earning ability 2 is from $50,000-$200,000;
- Earning ability 3 has an AGI of more than $200,000-$500,000;
- Earning ability 4 has an AGI of more than $500,000-$1,000,000; and
- Earning ability 5 has an AGI of more than $1,000,000 per year.

The share of household members by earning ability, q^e, is the share of returns per earning ability group. The labor productivity per earning ability, z_e, is the income per return for each earning ability with the labor productivity for group 1 being normalized to one. We take our Frisch elasticity estimate $\psi_e = 0.4$ from Reichling and Whalen (2012). The parameter D is set to match the observed average trade-balance to output ratio since $TB = i_{r,w}\frac{D}{y}$. We estimate tax rates similar to the methodology used by McDaniel (2007).[4]

The full list of parameters is included in the following section.

[2] The holding cost of capital is incorporated mathematically in the following way to steady state rental rate of capital:
$$r^*_{e,s} = \frac{\frac{1}{\beta} + \tau^k_e + \nu - (1-\delta)}{(1-(1-\eta^{i,r}_{e,t})\tau^{i,r}_e - \tau^{i,r,f}_e - \tau^{co} - \tau^s_s - \tau^o)}.$$
[3] Ohio Department of Taxation, ***Annual Report Fiscal Year 2018***.
[4] A complete explanation of the methodology is included in the Tax Model Parameters section.

Tax Model Parameters

Tax Rate Estimates

The state tax rates calculated are average Ohio tax rates. The general strategy employed is as follows. First, total income is categorized as labor income or capital income and private expenditures are categorized as consumption or investment. Second, tax revenues are classified as revenues generated from taxes on labor income, capital income, private consumption expenditures, or private investment. To find a given tax rate, we divide each category of tax revenue by the corresponding income or expenditure. Since we compute tax rates in the same fashion each year, we drop time subscripts for the rest of this section.

Data on tax revenues come from U.S. Census Bureau Survey of State Government Tax Collections (STC) and the Ohio Department of Taxation annual report for Fiscal Year 2018.[5] Data on income and expenditures come from regional BEA data. In any given year, total tax revenues collected by the government are the sum of taxes on production and imports (TPI), social security contributions, direct taxes on households (HHT), and direct taxes on corporations. The following sections detail the steps we take to categorize these tax revenues and calculate average tax rates.

Share of the Income Tax that Falls on Labor

The average tax rate on labor income is found by dividing labor income tax revenues by economy-wide total wage and salary labor income. To compute the labor income tax rate, we calculate labor income tax revenues and labor income. Labor income tax revenues come from two sources: the household income tax and social security taxes. However, household income taxes represent taxes on total income. Since only a portion of this income is generated from labor, only a portion of these taxes reflects taxes on labor income.

Unfortunately, the STC and BEA do not break down household income taxes according to type of income. For this reason, papers calculating average tax rates on labor and capital income based on aggregate data, such as Mendoza et al. (1994), assume that the tax rate on household labor income is the same as the tax rate on household capital income. We make the same assumption.

The federal income tax rate is found by dividing total federal taxes on income of the household, $FHHT$, by total household income in each period. Household income is defined as gross domestic product less net taxes on production and imports, or $GDP - (TPI - Sub)$. The household income tax rate is therefore measured as:

$$\tau^{i,f} = \frac{FHHT}{GDP - (TPI - Sub)}$$

It remains to divide income into payment to capital and payment to labor. Let θ be the share of income attributed to capital, with the remaining $(1 - \theta)$ share attributed to labor. Total household income taxes paid on labor income are represented by

[5] **2017 Annual Survey of State Government Tax Collections Detailed Table**, U.S. Department of Commerce, U.S. Census Bureau (Last visited January 14, 2019); and Ohio Department of Taxation, ***Annual Report Fiscal Year 2018***.

$$FHHT_L = \tau^{i,l,f}(1-\theta)\big(GDP - (TPI - Sub)\big)$$

The second source of tax revenue generated from taxes on labor income are social security taxes, SS. This corresponds to an exact entry in the BEA data, no further adjustment is required. Social security taxes combined with $HHTL$ represent total tax revenues that are classified as taxes paid on labor income, so the average tax rate on labor income is measured as:

$$\tau^{i,n,f} = \frac{SS + FHHT_L}{(1-\theta)\big(GDP - (TPI - Sub)\big)}$$

At the state level, we calculate income tax rates for a variety of earning groups. The state income tax rate is found by dividing total state taxes on income of the household, $SHHT_e$, by total household income in each period. Household income, total state taxes on income of the household, as well as population are distributed according to the distribution reported in the Ohio Department of Taxation annual report for Fiscal Year 2018.[6] Household income is defined as gross domestic product less net taxes on production and imports, or $GDP - (TPI - Sub)$. The household income tax rate is therefore measured as:

$$\tau^{i} = \frac{SHHT_e}{\big(GDP - (TPI - Sub)\big)_i}$$

It remains to divide income into payment to capital and payment to labor. Let θ be the share of income attributed to capital, with the remaining $(1-\theta)$ share attributed to labor. Total household income taxes paid on labor income are represented by

$$SHHT_{e,i} = \tau^{i,n}(1-\theta)\big(GDP - (TPI - Sub)\big)_i$$

The average state tax rate on labor income is measured as:

$$\tau^{i,n} = \frac{SHHT_{e,i}}{(1-\theta)\big(GDP - (TPI - Sub)\big)_i}$$

Consumption and Investment Tax Rates

Revenue collected from taxes levied on consumption and investment expenditures are included in taxes on production and imports, TPI. Consumption and investment expenditures are subsidized by the amount Sub. TPI includes general taxes on goods and services, excise taxes, import duties and property taxes. The task remains to properly allocate TPI to the relevant tax revenue category. This requires the proper division of TPI across consumption and investment. TPI includes the following components: Property taxes, general taxes on goods and services, excise taxes, taxes on specific services, and taxes on the use of goods to perform activities.

Some of the taxes included in TPI fall only on consumption expenditures. Others fall on both consumption and investment expenditures. Revenue from taxes that fall on both consumption and

[6] Ohio Department of Taxation, ***Annual Report Fiscal Year 2018***.

investment expenditures are assumed to be split between consumption tax revenue and investment tax revenue according to consumption and investment share in private expenditures. Taxes that fall strictly on consumption are excise taxes and taxes on specific services, reported as select sales taxes in the STC data.

Taxes that fall on both consumption and investment are general sales and use taxes, and taxes on use of goods to perform activities, which includes motor vehicle taxes, highway taxes, license taxes, etc. These goods are used in the production of both investment goods and consumption goods, and can be calculated by subtracting select sales taxes, total income taxes, and corporation license taxes from total taxes in the STC data.

After identifying taxes that fall strictly on consumption expenditures, we calculate λ, their share of TPI. Revenue collected from taxes levied on consumption expenditures is calculated as:

$$TPI_C = \left(\lambda + (1-\lambda)\left(\frac{C}{C+I}\right)\right)(TPI - Sub)$$

Consumption expenditures are reported in the national accounts gross of taxes. Taxable consumption expenditures are then $C - TPI_c$ and the consumption tax is measured as:

$$\tau^C = \frac{TPI_C}{C}$$

Since TPI_c represents revenue from consumption taxes, the remaining portion of $TPI - Sub$ is attributed to taxes on investment.

$$TPI_X = TPI - Sub - TPI_C$$

Share of the Income Tax that Falls on Capital

As calculated previously, income paid to capital in the economy is $\theta(GDP - (TPI - Sub))$. $OSGOV$ is gross operating surplus earned by the government, and therefore is not subject to tax. Taxable capital income is therefore $\theta(GDP - (TPI - Sub)) - OSGOV$. Capital tax revenues come from the following sources: the household income tax, and taxes levied on corporate income. Federal household taxes on capital, $FHHT_K$, is then

$$FHHT_K = \tau^{i,r,f}\theta\big(GDP - (TPI - Sub)\big)$$

The federal household capital income tax rate is then

$$\tau^{i,k,f} = \frac{FHHT_k}{\theta\big(GDP - (TPI - Sub)\big) - OSGOV}$$

Federal corporate tax data (FCT) is only available at the national level, therefore we first approximate the share of corporate tax paid by Ohio.

The federal corporate tax rate is computed using national data as:

$$\tau^{CT,F} = \frac{FCT}{\theta\big(GGDP - (TPI - Sub)\big) - OSGOV}$$

As owners of corporations, households are subject to all corporate taxation. The total federal capital income tax is then:

$$\tau^{i,r,f} = \tau^{CT,F} + \tau^{i,k,f}$$

At the state level household capital income tax is

$$SHHT_{K,i} = \tau^{i,k}\left(\theta\big(GDP - (TPI - Sub)\big)_i\right)$$

Where the household income and tax burden are once again distributed according to the distribution reported in the Ohio Department of Taxation annual report for Fiscal Year 2018.[7]

The state household capital income tax rate is then

$$\tau^{i,r} = \frac{\left(SHHT_{K,i} + SCT_i\right)}{\theta\big(GDP - (TPI - Sub)\big)_i - OSGOV_i}$$

[7] Ohio Department of Taxation, ***Annual Report Fiscal Year 2018***.

Sectors

Our model uses nine production sectors. The BEA reports GDP for each two-digit North American Industry Classification System (NAICS) industries, which we use to calculate each sector's percentage in total GDP (see Table B-4). Some of our sectors are the same as reported by the BEA, the remaining sectors are constructed by combining several NAICS industries as shown in Table B-1.

Table B-1: Definition of Sectors

Sector	NAICS Sectors
Agriculture, Forestry, Fishing, and Hunting	Agriculture, Forestry, Fishing, and Hunting
Mining	Mining
Utilities, Transportation, and Warehousing	Utilities Transportation and Warehousing
Construction	Construction
Manufacturing	Manufacturing
Trade	Wholesale Trade Retail Trade
Services	Information Finance and Insurance Professional, Scientific, and Technical Services Management of Companies and Enterprises Administrative and Waste Management Services Educational Services Arts, Entertainment, and Recreation Accommodation and Food Services Other Services
Real Estate, Rental, and Leasing	Real Estate Rental and Leasing
Health Care and Social Assistance	Health Care and Social Assistance

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Parameters

The following tables present the calibrated parameters for the model.

Table B-2: Household Parameters

Disutility of Labor	$\chi_e = 44$
Real Interest Rate*	$i_{r,w} = 0.04$
Annual Depreciation Rate of Capital	$\delta = 0.1$
Frisch Elasticity of Labor Supply	$\psi_e = 0.4$
Holding Cost of Capital	$\nu = -0.034$

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*The real interest rate is based on the difference between the nominal interest rate for three-month Treasury bill and the GDP deflator from 1950 to 2015 using St. Louis Federal Reserve Bank FRED data. The annual depreciation rate of capital is based on data from the BEA for the U.S. economy. It is the average of the sum of current cost depreciation in nonresidential private fixed assets and consumer durable goods divided by the sum of current cost net stock of nonresidential private fixed assets and consumer durable goods for the years 1963 to 2015. The Frisch elasticity of labor supply is based on the central estimate from Reichling and Whalen (2012).

Table B-3: Labor Productivity

Labor Productivity	Population Distribution
$z_1 = 1$	$q^1 = 0.60202$
$z_2 = 4.57$	$q^2 = 0.35917$
$z_3 = 13.07$	$q^3 = 0.02946$
$z_4 = 31.71$	$q^4 = 0.00559$
$z_5 = 288.01$	$q^5 = 0.00375$

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Table B-4: Sector Specific Parameters

Sector	Output Share	Employment Share	Capital Share
Agriculture, Forestry, Fishing, and Hunting	$\alpha_1 = 0.007$	$\mu_1 = 0.017$	$\theta_1 = 0.691$
Mining	$\alpha_2 = 0.007$	$\mu_2 = 0.004$	$\theta_2 = 0.516$
Utilities, Transportation, and Warehousing	$\alpha_3 = 0.054$	$\mu_3 = 0.042$	$\theta_3 = 0.369$
Construction	$\alpha_4 = 0.042$	$\mu_4 = 0.058$	$\theta_4 = 0.464$
Manufacturing	$\alpha_5 = 0.218$	$\mu_5 = 0.139$	$\theta_5 = 0.275$
Trade	$\alpha_6 = 0.143$	$\mu_6 = 0.168$	$\theta_6 = 0.314$
Services	$\alpha_7 = 0.317$	$\mu_7 = 0.400$	$\theta_7 = 0.356$
Real Estate, Rental, and Leasing	$\alpha_8 = 0.124$	$\mu_8 = 0.039$	$\theta_8 = 0.538$
Health Care and Social Assistance	$\alpha_9 = 0.089$	$\mu_9 = 0.132$	$\theta_9 = 0.317$

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Table B-5: Tax Parameters

Federal individual labor income tax rate for AGI 1	$\tau_1^{i,n,f} = 0.1141$
Federal individual capital income tax rate for AGI 1	$\tau_1^{i,r,f} = 0.0611$
Federal individual labor income tax rate for AGI 2	$\tau_2^{i,n,f} = 0.2099$
Federal individual capital income tax rate for AGI 2	$\tau_2^{i,r,f} = 0.1294$
Federal individual labor income tax rate for AGI 3	$\tau_3^{i,n,f} = 0.2668$
Federal individual capital income tax rate for AGI 3	$\tau_3^{i,r,f} = 0.1389$
Federal individual labor income tax rate for AGI 4	$\tau_4^{i,n,f} = 0.2330$
Federal individual capital income tax rate for AGI 4	$\tau_4^{i,r,f} = 0.1176$
Federal individual labor income tax rate for AGI 5	$\tau_5^{i,n,f} = 0.0719$
Federal individual capital income tax rate for AGI 5	$\tau_5^{i,r,f} = 0.0417$
State individual labor income tax rate for AGI 1	$\tau_1^{i,n} = 0.0125$
State individual capital income tax rate for AGI 1	$\tau_1^{i,r} = 0.0125$
State individual labor income tax rate for AGI 2	$\tau_2^{i,n} = 0.0280$
State individual capital income tax rate for AGI 2	$\tau_2^{i,r} = 0.0280$
State individual labor income tax rate for AGI 3	$\tau_3^{i,n} = 0.0392$
State individual capital income tax rate for AGI 3	$\tau_3^{i,r} = 0.0392$
State individual labor income tax rate for AGI 4	$\tau_4^{i,n} = 0.0455$
State individual capital income tax rate for AGI 4	$\tau_4^{i,r} = 0.0455$
State individual labor income tax rate for AGI 5	$\tau_5^{i,n} = 0.0488$
State individual capital income tax rate for AGI 5	$\tau_5^{i,r} = 0.0488$
General sales tax rate (effective rate)	$\tau^c = 0.0288$
Excise tax rate (effective rate)	$\tau^{ex} = 0.0138$
Severance tax rate (only applies to mining sector)	$\tau^s = 0.0230$
Corporate income tax rate	$\tau^{corp} = 0$
Franchise tax rate	$\tau^k = 0$
State tax revenues proportion of GDP	$\frac{TR}{Y} = 0.12$
Other state collections	$\tau^o = 0.0004$
Transfers from the federal government	$\frac{FF}{Y} = 0.12$

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Glossary of Terms

Calibrated – Matching the simulated model to the observable, real-life data by adjusting parameters to ensure the model represents the economy.

Capital adjustment cost – The time and monetary costs of changing the capital a firm uses, such as installing new machinery at a factory.

Capital share – Relative to labor, the proportion of output attributable to capital.

Cobb-Douglas production function – A simple production function in which different combinations of labor and capital quantities are used to obtain a certain quantity of product.

Comparative statics – A method of comparing different economic outcomes before and after a specified change.

Constant elasticity of substitution production function – A production function that assumes the elasticity of substitution is constant, meaning that a change in input factors will result in a constant change in output.

Debt elastic interest rate – An economy-wide interest rate that changes based on the economy's foreign debt holdings.

Depreciation rate – The rate at which capital, such as a car or computer, loses value over time.

Discrete – Measured as separate, distinct points in time, e.g., a person's age in years.

Dynamic scoring – A model that evaluates how changes in policy will change people's economic behavior, or the secondary impacts of a change (e.g., examining the employment and GDP changes that occur as a result of a policy change).

Elasticity – A measure of how the demand of a good responds to a price change for that good.

Employment share – The proportion of the working population employed in each sector of the economy.

Exogenous processes – External factors that influence household decisions.

Lagrangian function – A function that allows you to optimize a variable dependent on constraints, effectively combining a function being optimized with constraint functions.

Markets clear – The result when producers use the price that consumers are willing to pay for a product and there is no shortage or extra product.

Output share – The proportion of the total output of the economy produced by each sector.

Ponzi scheme – An investment fraud in which old investors are paid with money from new investors. Scammers often promise high returns with little or no risk.

Production function – An equation that shows how much product can be made from every combination of input factors, such as capital and labor.

Return on capital – Reveals how well a company is using its capital to make a profit.

Static analysis – A policy analysis that does not consider the economic behavior changes that may occur as a result of a policy change. Primarily, such analysis focuses solely on the changes to tax revenue due to a policy change without factoring in the human response to that change.

Steady-state capital-labor ratio – The ratio of the amount of capital to the amount of labor utilized for production when all markets clear in an economy.

Steady-state equilibrium – The economic choices and prices when market supply and demand are balanced and constant over time.

Stochastic economy – An economy that is affected by random, outside effects.

Tax instruments – The different ways that a government can levy a tax, or different types of taxes (e.g, corporate income tax, sales tax, and property tax).

Utility – The total gratification received from a person consuming a good or service. Economists use utility to capture individual’s preferences for differing goods and services. It is assumed that people want to maximize their utility.