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Working Paper

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Introduction and Summary

This paper provides a methodological overview of the framework for assessing the long-run impact of the changes in tax-benefit system. The framework enables a transparent ceteris-paribus evaluation of reform scenarios and we expect it to become a practical tool for expert discussion on tax-benefit reforms, including the parameters following up a new law of income tax. In the present work, we have focused on key macroeconomic indicators (gross domestic product, consumption, and wage bill) as these are the key inputs for the current activities of the Ministry of Finance, but the analysis easily extends to other fields of interest such as redistribution, welfare or income poverty measures.

The framework has three related building blocks. The first one is a microsimulation tool of the tax-benefit system which accounts for most of the taxes and benefits featured in the Czech welfare system. The second block employs the output of microsimulation tool to estimate consequent change in the labour supply of the individuals. It is a structural probit model which assigns probability of participation in the labour market to individuals based on their socio-demographic characteristics, wage, and non-labour income. The third block is a simple general equilibrium model where it is possible to model long-run macroeconomic relationships between gross domestic product, gross wage bill, net disposable income of households, and other macroeconomic indicators. Although we do not explicitly compute distributional impact of the simulated scenarios, the framework could be easily extended in this direction.

An essential feature of our framework is the feedback effect from the general equilibrium model (block 3) to the microeconomic estimation of the labour supply (block 2). This iterative nature of the estimation helps to robustly capture the impact of a labour supply shock, re-estimating the change in aggregate labour supply and follow-up adjustment in wages until the economy converges in a new long-run equilibrium. In the empirical part of the paper we model the impact of five different changes in the tax-benefit system and report their respective long-run effects. We base our estimates on the dataset from the SILC survey carried out every year across the European Union. The latest version of the dataset consists of surveys from 2011 to 2016.

Our approach builds upon several studies applying similar methodology. Siebertová et al. (2014) capture the tax-benefit system in Slovakia. Siebertová et al. (2015) then employ the tax-benefit model to estimate the elasticity of labour supply to changes in wages and transfers, while Galuščák and Kátay (2019) provide corresponding estimates in a comparative study of the tax-benefit systems in the Czech Republic and Hungary. Benczúr et al. (2018) use the full framework including feedback from general equilibrium model. As a microsimulation tax-benefit calculator, there are currently several popular tools available for non-commercial use. Many authors refer to the microsimulation model for the European Union (EUROMOD), while Organisation for Economic Co-operation and Development offers its tax-benefit calculator too. We choose to code a specific package of tax-benefit functions that allows for more flexibility with the estimations.

The structure of the paper is following. In the next section, we briefly discuss related literature. We then continue with an exposition of the labour market model and links between the microsimulation model and the general equilibrium part of the model in Section 2. We also describe the algorithm of the estimation there. Section 3 presents the results of alternative scenarios and Section 4 demonstrates the robustness of our calibration procedure. Section 5 concludes and outlines possible extensions of our framework. Finally, there are several technical appendices which provide details of the model - its derivation, calibration of the parameters as well as considered tax-benefit components. Our detailed exposition of the relevant steady-states is unique and allows for an analytical solution without necessity of nonlinear optimization.

1 Related Literature

The framework we present consists of three building blocks whose coverage varies in the literature. The tax-benefit models enjoy the least popularity in the academic field although they are a cornerstone for various policy evaluations. Publications which single out such models are rare and usually come from policy-making institutions. In contrast, the second block where we build a labour supply model is explored frequently with many different implementations. Our final estimation block is the general equilibrium (GE) model with a feedback effect from the previous micro-simulation labour-supply block. Conceptually, this approach is not new, but our specific application is uncommon and computable general equilibrium (CGE) models are more traditional in this field.

The tax-benefit models similar to ours are usually country specific tools for capturing the effect of changes in the social security systems. Siebertová et al. (2014) present such a model for Slovakia and Steiner et al. (2012) model tax-benefit system in Germany. In the case of the Czech Republic, the applications simulating tax-benefit include Galuščák and Kátay (2019), Galuščák and Pavel (2012), Dušek et al. (2013), Janský et al. (2016). All models capture the system in their examined period respectively, but they are generally very similar in the components of the tax-benefit system they consider. The impact of major tax and benefit reforms adopted in the Czech Republic before 2009 was analysed by Hrdlička et al. (2010). The authors have analysed average and marginal effective tax rates for different groups using a modified version of the OECD Tax and Benefit Model.

We provide details of our tax-benefit model below and we follow the suit of above-mentioned authors with the main addition in parametrizing the model for several years (2011–2016). Notably, Sutherland and Figari (2013) present the tax-benefit microsimulation model for the countries in the European Union (EUROMOD). The model simulates individuals' and households' tax liabilities and benefit entitlements given the rules in each member state. For the most recent version of the EUROMOD implementation for the Czech Republic, we refer to Kalíšková et al. (2018). While EUROMOD is flexible tool for either retrospective or ex-ante analysis of policy changes, it is not well-suited for our purposes. We could technically use it to examine the static effects of various scenarios on inequality/poverty measures, but we are also interested in the impact on the labour supply and, more importantly, in the feedback effect between microsimulation and GE part of the framework. The latter is difficult to implement, and the complexity of our approach drives the choice to develop a unique tax-benefit simulation tool compatible with remaining blocks of the framework. In the same line we cannot rely on other existing tax-benefit models developed earlier, such as TAXBEN by Dušek et al. (2013).

Our framework relates to modelling of behavioural responses in labour supply. Aaberge and Colombino (2014) provide a thorough overview of the approaches since the inception of microsimulation from reduced-form models, which lacked standard theoretical microeconomic foundations, up to modern structural discrete choice models. Throughout their development, the structural labour supply models were applied to address the responses to introduction of flat tax (Fuest et al., 2008), basic income (Clavet et al., 2013), an effect of in-work benefits and tax credits (Aaberge and Flood, 2013), changes in child care policy (Van Klaveren and Ghysels, 2012), or optimal taxation (Blundell and Shephard, 2012)[1].

We rely on structural discrete choice approach exposed in Benczúr et al. (2014), where the individual maximizes the utility from consumption and leisure while facing a constraint by wage and non-labour income. Our focus is on the extensive margin, i.e. the change in the probability of participation in the labour market. There is an optional choice to account for the change in hours worked - the intensive margin of the labour supply - based on the income tax elasticities. The quantitative effect of the intensive margin is, however, very limited and therefore, we neglect it in baseline estimations.

The models which are methodologically closest to our approach include Siebertová et al. (2015), who find that 1% increase in net wage raises the probability of economic activity by 0.26 percentage point (pp) while the same change in transfers decreases participation probability by -0.04 pp. These numbers are quite close to the ones reported by Galuščák and Kátay (2019) and Benczúr et al. (2014) who estimate the wage elasticities[2] in the range between 0.24 and 0.34. The reaction to transfers also shows a similar magnitude with Czech and Hungarian labour markets being slightly more sensitive to the change in transfers (-0.12). The proximity of these estimates arises from the similar methodological approach.

The estimates of wage elasticity of labour supply differ across literature. A pioneering study on the U.K. General Household Survey by Arrufat and Zabalza (1986) explored the participation elasticity of married women and arrived at

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[1] We refer interested reader to Aaberge and Colombino (2014) who provide an exhaustive list of applications.

[2] Our term "elasticity" stands for percentage change of labour supply in response to 1% increase of net wage (if not stated otherwise).

the value of 0.14. Kimmel and Kniesner (1998) employ the dataset of Survey of Income and Program Participation in the US and estimate the employment elasticities of 0.6, 2.4, 1.8 and 1.1 for single men, single women, married women, and married men respectively. Other values have been put in place by Aaberge et al. (1999) using Italian data. They conclude that elasticities differ significantly by gender and provide values of 0.04 for men and 0.65 for women. These values show much more variability both due to varying methodologies as well as due to their focus on subgroups of the population. Additional differences in estimates can be explained by country and period of examination, which likely captures the change in preferences; see Bargain and Peichl (2013). Reviewing additional evidence on elasticities and their development in time, McClelland and Mok (2012) point to decreasing elasticity of married women, although it remains higher than that of men and single women. They further report higher elasticity of lower-income workers, especially for the extensive margin. Chetty et al. (2012) also examine various estimates and their meta-analysis provides a consensus value of extensive margin elasticity around 0.25. They argue in favour of using it for calibration of macro models.

The third block of our framework is a GE model. Cockburn et al. (2014) present motivations for micro-macro modelling and describe the evolution and types of models in this area. Traditionally, the policy makers are interested in the impact of macro policy reforms, but the impact is often heterogeneous across households or production sectors in the economy. Any macroeconomic model which only simulates aggregate effects and ignores this heterogeneity will fail to capture potentially crucial effects of a policy reform such as changes in the income distribution. The models commonly combine the micro models applied to large representative surveys of population with the CGE approach. A combination of these perspectives captures the redistributive effects and short-run changes through the microsimulation part, and account for long-run general equilibrium effects of the reforms through the macroeconomic model.

In terms of application, there are several options how to integrate microsimulation with macroeconomic model. The microsimulation may be fully integrated with the macroeconomic part. In this case, the representative households are replaced by many households from a survey while the model structure remains the same. The difficulty lies in aligning the microeconomic data on consumption and income to the aggregates employed in the CGE model. This generally means summing up consumption expenditures by broader categories and income by its sources. The difficulty of alignment is the principal problem in application of this approach. Additionally, the CGE framework has limited possibilities of behavioral functional forms. As an example, the discrete choice model of employment cannot be captured; see Cockburn et al. (2014). The other options are top-down and bottom-up. Their drawback is in the one-way effect from either the computed macro shock (top-down) to the micro-level or the one-off aggregated micro shock to the macro model (bottom-up). While the former ignores the behavioral change following the macro shock, the latter abstracts from the general equilibrium effects of the microsimulation. Ideally, one would like to have a feedback effect between the two parts of the model and this is what is implemented in the iterative method of micro-macro modelling. This procedure interacts the initial shock from either layer of the model to the other and then iteratively evaluates it until the models converge to predefined conditions.

In this paper, we rely on a variant of iterative approach between a small GE model of an open economy and behavioral discrete choice model of labor market participation. The choice of GE model over CGE lies in the relative ease of implementation and tractability of the model. Davies (2009) presents conditions under which CGE model framework could be superseded by the GE approach. He stresses the openness of the economic unit of examination as the key condition to rely on a pure macro model. Our macroeconomic model mirrors the application of Benczúr et al. (2018), who focus on the long-run macroeconomic effects of tax-benefit changes in Hungary. A few other notable contributions in micro-macro literature exist. Peichl (2009) reviews the combination of the two layers and examines the consequences of flat-tax introduction in Germany. The impact of a welfare reform in Germany is also central for Arntz et al. (2008), who compare the effects under aggregated and disaggregated (considering more household types) version of the model. They conclude with a preference for a more disaggregated approach. Earlier studies include Cameron and Ezzeddin (2000) where Canadian microsimulation model is supplemented with a macro effects using social accounting matrix multipliers. A promising development in the field of combining micro and macro models lies in constructing the model which is able to credibly capture the transition path from one equilibrium to another. In other words, to simulate the development in time perspective on the top of comparative analysis. The recent contribution by Horváth et al. (2018) steps in this direction and presents a dynamic general equilibrium model with a microsimulation part. Barrios et al. (2019) combine the QUEST (dynamic stochastic general equilibrium model) and EUROMOD (tax-benefit microsimulation) models of the European Commission and apply the framework to simulate the effects of social insurance contributions reform in Belgium, but they rely only on bottom-up approach to the simulation.

2 Micro-macro Model Framework

2.1 Labour Market Participation

We adopt the labour supply model from Benczúr et al. (2014). The authors build their model on standard utility maximization problem defined as a trade-off between leisure and consumption:

$$\max U(c, 1-l) = \frac{c^{1-\psi}-1}{1-\psi} + \chi\frac{(1-l)^{1-\varphi}}{1-\varphi}$$

$$\text{s.t.} \qquad c + w(1-l) = w + NY \tag{1}$$

where *c* is consumption, l is labour, *w* is wage and *NY* denotes other non-labour income including the income of other members of the household. χ captures utility derived from a unit of leisure relative to the unit of consumption. We normalize the total endowment to 1, i.e. leisure is $1-l$ and expresses a portion of time dedicated to out-of-work activities. The budget constraint (1) can be derived from consumption that is financed by labour and other income

$$c = wl + NY \tag{2}$$

$$c - wl + w = w + NY \tag{3}$$

$$c + w(1-l) = w + NY \tag{4}$$

Optimality condition is then expressed as

$$\chi(1-l)^{-\varphi} = wc^{-\psi}. \tag{5}$$

We are interested in reservation wage w_{res} which is defined as a threshold for accepting a job offer and corresponds to a condition $1-l^* = 1$. This implies $c^* = NY$ and $w^*_{res} = \chi NY^{\psi}$ gives the reservation wage. Participation assignment then depends on $w \geq w^*_{res}$. Reformulated in logs

$$\log w \geq \log\chi + \psi\log NY. \tag{6}$$

We then expand $\log\chi_i = \boldsymbol{Z_i}\boldsymbol{A}' + \varepsilon_i$, where $\boldsymbol{Z_i}$ is a vector of observable individual characteristics, $\boldsymbol{A}$ is a vector of coefficients (shared across individuals) and $\varepsilon_i \sim N(0, \sigma^2)$:

$$\log w_i - \boldsymbol{Z_i}\boldsymbol{A}' - \psi\log NY \geq \varepsilon_i \tag{7}$$

and finally, we can express the probability of someone working when offered wage w_i given non-labour income NY_i and individual characteristics $\boldsymbol{Z_i}$:

$$P = \Phi\left(\frac{\log w_i - \boldsymbol{Z_i}\boldsymbol{A}' - \psi\log NY_i}{\sigma}\right) = \Phi(\gamma\log w_i - \boldsymbol{Z_i}\boldsymbol{\alpha}' - \psi'\log NY_i) \tag{8}$$

after an appropriate rescaling. In the next step, we add transfers and taxes into the framework. This leads to a redefinition of reservation wage but at the same time it constraints the participation decision of an individual to a full-time job l^*. Reservation wage is then set as follows:

a) not working: $c^* = NY$, $1-l^* = 1$, utility is $\frac{NY^{1-\psi}-1}{1-\psi}$

b) working l^*: $c^* = NY - \Delta NY + wl^*$, utility is $\frac{(NY-\Delta NY+wl^*)^{1-\psi}-1}{1-\psi} + \chi\frac{(1-l^*)^{1-\varphi}}{1-\varphi}$

with ΔNY being a balance of paid taxes and received benefits between not working and working. Using gains-to-work, $GTW = wl^* - \Delta NY$, we can set up the comparison

$$\frac{(NY+GTW)^{1-\psi}-1}{1-\psi} - \frac{NY^{1-\psi}-1}{1-\psi} \geq -\chi\frac{(1-l^*)^{1-\varphi}}{1-\varphi}. \tag{9}$$

We can approximate the left-hand side of (9) to $NY^{-\psi}GTW$[3]. Substituting $Q = \frac{(1-l^*)^{1-\varphi}}{1-\varphi}$ and taking logs, we get to a similar condition as previously:

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[3] First-order linear approximation around GTW = 0.

$$\log GTW - \psi \log NY - \boldsymbol{Z_i A'} + \log Q \geq \varepsilon \tag{10}$$

leading to a structural probit equation of the same form as in (8). We describe the estimation results, including a list of individual characteristics in Appendix A.

2.2 General Equilibrium

Our general equilibrium macro model is a long-run model of a small open economy and follows the structure of Benczúr et al. (2018). Capital supply is very elastic, while capital and labour are paid their marginal products based on a constant-returns-to-scale production function. The model does not consider changes in sectoral consumption patterns nor does it try to capture the behaviour of the household sector since the labour supply shock comes from the microsimulation and structural probit model described in the previous subsection.

The production function of the representative firm exhibits constant elasticity of substitution:

$$Y = F(K, L) = \left(\alpha K^{\beta} + (1-\alpha) L^{\beta}\right)^{1/\beta} \tag{11}$$

where the standard production function notation applies, K stands for capital and L for labour, α is share of capital and β is a substitution parameter such that $\beta = (\sigma - 1)/\sigma$ where σ is elasticity of substitution between capital and labour. Firms maximize profit

$$\pi(K, L) = \left(\alpha K^{\beta} + (1-\alpha) L^{\beta}\right)^{1/\beta} (1 - \tau_s) - w(1 + \tau_w) L - \tfrac{r}{1-\tau_k} K \tag{12}$$

where τ_s is the effective tax rate on sales (the effects of local business tax), w is the gross wage[4], τ_w is the employer-side social security contributions (payroll tax), τ_k is the effective tax rate on capital and $\frac{r}{1-\tau_k}$ is the net user cost of capital.

Optimization with respect to K and L yields 2 equations in log-linearized form resulting from first order conditions:

$$\tilde{k} = \tfrac{1}{(1-\beta)\bar{k}^{-\beta}} \left(\tfrac{1}{\alpha}\right)^{\frac{1}{1-\beta}} \left(\tfrac{\bar{r}}{\overline{(1-\tau_k)(1-\tau_s)}}\right)^{\frac{\beta}{1-\beta}} \left(\tilde{r} - \left(\widetilde{1-\tau_k}\right) - \left(\widetilde{1-\tau_s}\right)\right) + \tfrac{1}{\alpha}\tilde{k}, \tag{13}$$

$$\tilde{k} = \tfrac{1}{\alpha \bar{k}^{\beta}} \left(\tfrac{1}{1-\alpha}\right)^{\frac{\beta}{1-\beta}} \tfrac{1}{1-\beta} \left(\tfrac{\overline{w}\,\overline{(1+\tau_w)}}{\overline{1-\tau_s}}\right)^{\frac{\beta}{1-\beta}} \left(\widetilde{w} + \left(\widetilde{1+\tau_w}\right) - \left(\widetilde{1-\tau_s}\right)\right). \tag{14}$$

The model is closed by the equation that determines the aggregate supply of capital. Capital is provided by an international capital market and its supply is modelled in a reduced form

$$\widetilde{K} = \eta \tilde{r} \tag{15}$$

where η is the elasticity of capital supply K with respect to the after-tax rate of return r.

In the preceding equations, k is the capital-labour ratio, $\bar{x}$ denotes the ex-ante equilibrium ("steady state") of variable x and $\tilde{x} = \frac{x-\bar{x}}{\bar{x}}$ represents a deviation from the long-run equilibrium. Equations (13) and (14) ensure that return to capital is equal to its marginal product and wage is equal to the marginal product of labour, respectively. Labour shock $\tilde{L}$ is an output of the microsimulation. The capital-labour ratio can be approximated as

$$\tilde{k} \approx \widetilde{K} - \tilde{L}. \tag{16}$$

Details on derivation can be found in Appendix D. The calibration process is described in Appendix B.

2.3 Algorithm of Policy Simulations

Our goal is to demonstrate the capabilities of the framework by simulating several changes in the tax-benefit system. We focus on the scenarios which alter the universal tax credit, personal income tax, social security contributions, and unemployment benefits. On the top of that, we also simulate the macroeconomic and distributional effects of the progressive income taxation with the tax brackets equal to the ones effective before introduction of the flat tax in 2007. The simulation mechanism applies changes to the tax-benefit system. Ultimately, the effects transmit into net

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[4] In microsimulation part, we used the same letter w for the net wage. Our code correctly deals with this difference.

wage and transfers which alters the labour supply of the individuals. Next, we sum the individual labour supply changes into an aggregate labour supply shock which we feed into the macro-part of the framework. In detail, the simulation proceeds as follows:

1. given the changes in the tax-benefit system, we first run a microsimulation under this alternative scenario. In other words, we use our tax-benefit framework to determine how much each individual gains or loses as a consequence of the changes. We update financial gains to work and the hypothetical amount of transfers one would get at no hours worked,
2. we combine these updated measures with the coefficients of baseline structural probit estimation yielding a change in the individuals' probability of being active on the labour market. We obtain aggregate labour supply shock by summing up the changes in labour supply weighted by their sampling weights,
3. we feed this shock into the macro model, which calculates general equilibrium effects on the wages and capital stock,
4. a microsimulation is repeated based on the GE change of the wage level[5]. This iterative process continues until convergence, i.e. until the GE of the economy is consistent with the labour supply shock induced by the reform,
5. finally, we compare the new steady-state values of macroeconomic variables (GDP, labour supply, wage bill, consumption) with the no policy change scenario and compute the relative differences.

2.4 Fiscal effect

The household's income-related taxes and benefits (most importantly individual income tax, social security contributions or unemployment benefits) are model-driven, other items (for instance VAT collection, pensions) are taken simply as a fixed portion of nominal GDP. Change in other items therefore corresponds to an estimated nominal GDP growth, which we calculate as a real growth (model works with real output) inflated by average annual change in GDP deflator (1.3% over the period 2011–2016). This may be interpreted as a rule of the fixed effective tax rate on exogenous fiscal items which is consistent with the neutral policy assumption. It should be also noted that our model is supply-driven and effect on household consumption is rather mechanical through the impact on their disposable income. We do not account for any heterogeneous consumer's response to a particular tax-benefit change in our results. In particular, we do not model the consumption-saving behaviour of the households and assume that any change in disposable income of households is reflected in household consumption. This may potentially inflate the effect of the examined policy changes on the VAT and overestimate their fiscal impact. These assumptions mirror the ones in Benczúr (2018) and Siebertová (2015).

2.5 Labour Intensity

As already mentioned, we consider the fixed job size equivalent to a full-time job. Some authors suggest taking into account working hours (intensive margin) as well. We adopted an iteration procedure described by Kiss and Mosberger (2015) who use estimation based on individual marginal (METR) and average (AETR) effective tax rates

$$\Delta\log w = \alpha\Delta\log(1 - METR) + \beta\Delta\log(1 - AETR), \tag{17}$$

where w is a gross wage. While coefficient α captures an additional working activity if one faces a lower marginal tax rate, β represents the income effect from taxation and received transfers. We apply the resulted change from (17) also to working hours. The iteration continues until maximum difference in hours from a previous round (in absolute value) is lower than a small constant (0.1%). New equilibrium wage and hours of work (intensive margin) are established complementing probabilities of being active.

Some authors assume an intensive margin response only for the top income quintile. We tried to run the model with intensive margin for all groups but the impact of this module has proven to be negligible (as documented below in Table 2). Consequently, we do not assume intensive margin reaction in current simulations. As an easy empirical verification of low flexibility in working hours, we need to mention a very small share of part-time employment in the Czech Republic (on average 5.3% in 2011–2016).

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[5] Gross wages, pensions, other income (e.g. income from rent) and fringe benefits are all multiplied by $(1 + \tilde{w})$.

3 Application on Alternative Scenarios

3.1 Changes in Basic Policy Parameters

For illustration purposes, we present the results of five scenarios where we vary basic tax-benefit parameters. Scenario 1 models the 10% increase in universal tax credit (HUTC). Scenario 2 and scenario 3 portray the long-run effects of change in the personal income tax rate by -3 (ITRC) and 3 (ITRH) pp, respectively. Scenario 4 captures an increase in social security contributions on the employee side to 14.5%[6] (SSCI). Scenario 5 reflects a more generous unemployment benefit; each individual now receives a higher ratio of her previous net wage by 20 pp (UBI). This represents one of the discussed measures taken in case of economic recession and the other scenarios aim to examine viable policies which might be considered by the government. The results come from a comparative statics exercise and follow the algorithm of policy simulations described above. In essence, they capture the differences between two long-run equilibriums under alternative tax-benefit systems.

Table 1: Long-run Effects of Simulated Scenarios

		HUTC	ITRC	ITRH	SSCI	UBI
Labour supply	*growth in %*	0.3	0.8	-1.2	-1.2	0.0
Wage bill	*growth in %*	0.1	0.1	-0.3	-0.4	0.0
Household consumption	*growth in %*	0.1	0.1	-0.3	-0.3	0.0
GDP	*growth in %*	0.1	0.3	-0.6	-0.6	0.0
Fiscal balance	*bil. CZK*	-22.6	-72.7	60.6	64.6	-10.4

Note: Wage bill, household consumption and GDP are in real terms. Fiscal balance shows the net lending/borrowing of general government in the National Accounts Methodology).
Source: Calculations of the authors.

The results mentioned above show the relative difference between an alternative and a baseline scenario, where the baseline represents the initial long-run equilibrium under the current tax-benefit schedule in the Czech Republic. The model is nonlinear in all components and thus asymmetry in results of scenario 2 and 3, which both capture the change in personal income tax rate, is not surprising. The impact of scenario 4 is very slightly higher than that of scenario 3 since the change in social security contributions directly affects earnings from work. The higher personal income tax rate is virtually neutral for some low-income workers due to their zero or even negative tax base and these people create a core of extensive margin frontier. Higher unemployment leads to a very slightly negative macroeconomic impact (invisible up to the first decimal point) but it comes with a significant burden on public finances.

Table 2 shows results of the same scenarios with working hours' response across the whole distribution. Differences from the results in Table 1 are hardly discernible.

Table 2: Long-run Effects with Working Hours' Response

		HUTC	ITRC	ITRH	SSCI	UBI
Labour supply	*growth in %*	0.3	0.9	-1.1	-1.1	0.0
Wage bill	*growth in %*	0.1	0.3	-0.4	-0.4	0.0
Household consumption	*growth in %*	0.1	0.2	-0.3	-0.3	0.0
GDP	*growth in %*	0.1	0.5	-0.6	-0.6	0.0
Fiscal balance	*bil. CZK*	-22.6	-73.2	58.8	62.7	-10.4

Source: Calculations of the authors.

3.2 Progressive Income Tax Brackets

In the next scenario, we applied a progressive income tax regime with four consecutive brackets and rates (holding other parameters including tax allowances fixed). We have been inspired by a progressive tax regime in the Czech Republic before a major tax reform in 2008. The tax brackets are related to tax base without allowances (gross income and employer's social security contributions). We inflated the brackets (their bounds) by the average wage growth occurring since then and report them in Table 3. The corresponding taxation applies to the portion of income which is

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[6] An increase of 3.5 pp.

above a bracket. Marginal statutory tax rate (excluding benefits and allowances) is therefore a piece-wise constant function of gross income.

Table 3: Simulated Progressive Tax Design

		Bracket 1	Bracket 2	Bracket 3	Bracket 4
Tax base (annual income)	*CZK*	0–152,600	152,601–305,200	305,201–462,900	462,901+
Tax rate	*%*	15	20	25	32

Source: Calculations of the authors.

Table 4 shows impact of our designed progressive tax scheme. The results suggest positive fiscal impact through burdening high-earners while other key macroeconomic figures would deteriorate. The higher complexity of a tax regime poses additional channels of behaviour adaptation from which usual models abstract.

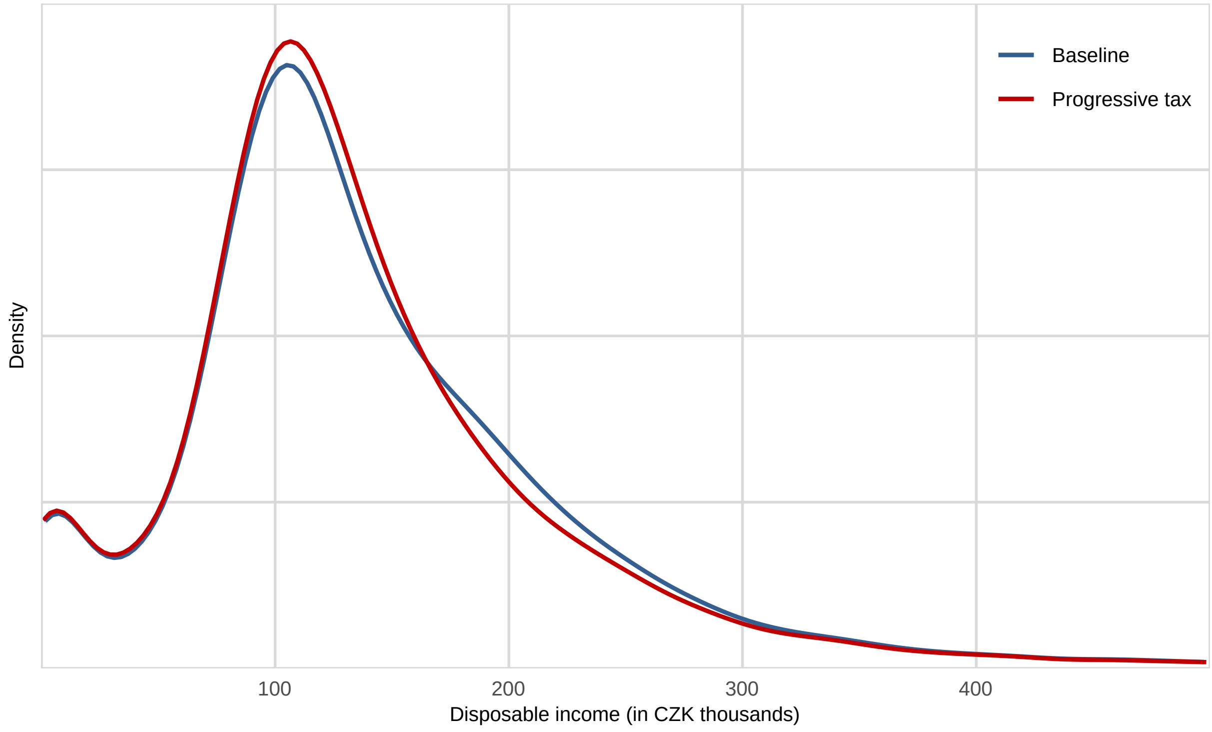
Table 4: Effects of Hypothetical Progressive Tax Regime

Labour supply	*growth in %*	-1.0
Wage bill	*growth in %*	-0.3
Household consumption	*growth in %*	-0.3
GDP	*growth in %*	-0.5
Fiscal balance	*bil. CZK*	45.6

Source: Calculations of the authors.

The effects of progressive tax scheme on income distribution may be illustrated with an estimated distribution. We use an expected income which is taken as a weighted average of net labour income and income from being inactive where weights are probabilities of being (in)active. In this case reform scenario affects expected income in two ways: by lowering net income from work and also probability of being active through lower gains-to-work. Graph 1 compares kernel density estimates of both pre-reform and post-reform individual incomes. While there is a shift of the income distribution to the left, low-incomers are virtually unaffected in line with nonlinearities due to tax allowances. It can be shown that more stringent set of the brackets leads to significant change in distribution and adverse macroeconomic effects as expected.

Graph 1: Impact of Progressive Tax Scheme on Income Distribution



Note: Gaussian kernel density estimates at 1000 points.
Source: Calculations of the authors.

4 Calibration Robustness Check

Impact of calibrated parameters in the general equilibrium framework might be a disputable feature of the model. We describe a detailed methodology of calibration in a reproducible manner in Appendix B. Although some parameters are bounded in their nature or by the theory, a grid of their possible discretized values grows at an exponential pace with the higher number of parameters. Hence, sensitivity analysis capturing most theoretical variations is not feasible in practice. Also, our calibration process was done coherently and excludes contradictory combinations of parameter values.

Instead of a varying multidimensional vector, we utilized calibrated parameters from comparable studies. We report results for the first three scenarios (see Section 3) and different sets of calibrated parameters (listed in Appendix B). According to this simplified analysis, the model appears to be insensitive on a different calibration from other relevant studies at least in case of relatively small tax-benefit changes.

Table 5: Higher Universal Tax Credit with Alternative Calibration (10% increase)

		MF ČR (2020)	Benczúr et al. (2012)	Siebertová et al. (2015)
Labour supply	*growth in %*	0.3	0.3	0.3
Wage bill	*growth in %*	0.1	0.1	0.1
Household consumption	*growth in %*	0.1	0.1	0.1
GDP	*growth in %*	0.1	0.2	0.2
Fiscal balance	*bil. CZK*	-22.6	-22.9	-23.0

Source: Benczúr et al. (2012), Siebertová et al. (2015). Calculations of the authors.

Table 6: Income Tax Rate cut with Alternative Calibration (-3pp)

		MF ČR (2020)	Benczúr et al. (2012)	Siebertová et al. (2015)
Labour supply	*growth in %*	0.8	0.9	0.8
Wage bill	*growth in %*	0.1	0.3	0.1
Household consumption	*growth in %*	0.1	0.2	0.0
GDP	*growth in %*	0.3	0.6	0.5
Fiscal balance	*bil. CZK*	-72.7	-74.5	-74.8

Source: Benczúr et al. (2012), Siebertová et al. (2015). Calculations of the authors.

Table 7: Income Tax Rate hike with Alternative Calibration (+3pp)

		MF ČR (2020)	Benczúr et al. (2012)	Siebertová et al. (2015)
Labour supply	*growth in %*	-1.2	-1.2	-1.2
Wage bill	*growth in %*	-0.3	-0.4	-0.3
Household consumption	*growth in %*	-0.3	-0.3	-0.2
GDP	*growth in %*	-0.6	-0.8	-0.8
Fiscal balance	*bil. CZK*	60.6	62.3	63.4

Source: Benczúr et al. (2012), Siebertová et al. (2015). Calculations of the authors.

5 Conclusion

In this paper, we describe the simulation framework to model the impact of changes in the tax-benefit system. The framework enhances the capacity to analytically evaluate both simple and complex modifications in tax and social security system. We build on the work of Benczúr et al. (2018) and adapt their approach to the Czech Republic. The simulation consists of three different parts. It begins with the tax-benefit microsimulation, i.e. computation of the effect hypothetical changes in the tax-benefit system may have on the representative set of households. In the second step, we evaluate the impact of the resulting change on gains-to-work and non-labour income of the individuals and estimate the behavioural effect in terms of their adjusted probability of participation in the labour market. We then aggregate the individual differences in labour supply into an aggregate labour supply shock which we feed into a small general equilibrium model of an open economy to estimate the general equilibrium effects on macroeconomic variables and on wages in particular. Finally, we feed the wage shock from the macro model back into our microsimulation and iterate the procedure until the GE model converges into a new long-run equilibrium.

We provide a detailed description of the framework and present simulations of five different scenarios. The selection of demonstrated scenarios is not comprehensive, but we resort to tax-benefit adjustments frequently discussed by policymakers. In particular, we show the effect of changes in personal income tax rate (+- 3pp), 10% increase in universal tax credit, an increase of the social security contributions on the side of an employee to 14.5%, and increase of unemployment benefit (higher ratio of previous net wage by 20 pp). Additionally, we present a simulation of a progressive tax regime where we adopted wage inflated tax brackets from the period before large tax reform in 2008. We show a positive fiscal impact of the progressive scheme accompanied by the negative impact on macroeconomic variables. The specific point estimate should be, however, interpreted with caution as a higher tax rate incentivizes optimization for which we cannot control.

Alongside the illustration of the output of the simulation framework, we document several phenomena in the responses to the changes in tax-benefit system in the Czech Republic. By considering the equal change of personal income tax in both directions from current 15%, we show the asymmetry in the workers' adjustment of labour supply. In particular, low-income earners are neutral to increases in the personal income tax due to their very low or even negative tax base. Similar effect is present in the simulated introduction of progressive tax schedule. The bottom part of the distribution is hardly affected while the largest shift occurs between 5th and 9th income decile. Lastly, we capture the negligible impact of the increased unemployment benefits' ratio on workers' labour supply. As a robustness exercise, we check the sensitivity of the universal tax credit scenario by varying calibrated parameters of the GE model and adopting values from the related papers by Benczúr et al. (2012) and Siebertová et al. (2015) and find no significant discrepancies from our main estimates.

The current version of the model is ready for policy simulations, but we see potential paths for improvement. Most notably, the income distribution from SILC could be adjusted by an empirical income distribution using individual data on tax or social security collection. Accuracy of our survey data on social benefits could benefit from linking them to administrative data as documented by Meyer and Mittag (2019). Ideally, this should be a coordinated effort of the Ministry of Finance, the General Financial Directorate, and the Czech Social Security Administration. We need to acknowledge that we simplify the simulated tax-benefit system in several important ways: we do not consider solidarity tax, treat self-employed as employees, and leave other gross income of individuals untaxed. Additionally, the GE part of the model may be carefully extended to include adjustment costs for changes in capital and labour, depreciation, or some measure of the price level. We could also consider an explicit theoretical model of the labour market as in Siebertová et al. (2015), and a more complex model could include main economic sectors and capture their spillovers and interactions. The labour supply shock from structural probit estimation could enter into a dynamic stochastic general equilibrium model to explore the dynamic properties of the shocks in line with recent developments in the field of micro-macro modelling. We believe most of these improvements may be gradually built into the framework.

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Appendix A: Structural Probit Estimation

Table 8: Probit Estimation Results

Variable	Description	Coefficient
logGTW	logarithm of gains-to-work	3.200 ***
		(0.095)
logNY	logarithm of non-labour income	-1.108 ***
		(0.023)
female		-0.458 ***
		(0.024)
edu_second	secondary education	-0.395 ***
		(0.034)
edu_tert	tertiary education	-1.031 ***
		(0.056)
age_25minus	age ≤ 25	0.137 ***
		(0.045)
age_50plus	age ≥ 50	-0.565 ***
		(0.053)
work_experience	previous working experience (yes or no)	0.062 ***
		(0.002)
chron_disease	chronical disease (yes or no)	-0.133 ***
		(0.047)
mom_child_under3	mother with a child under 3 years old (yes or no)	-1.508 ***
		(0.038)
pensioner		-3.641 ***
		(0.042)
student		-3.266 ***
		(0.056)
fam_married	family status: married	-0.282 ***
		(0.034)
fam_divorced	family status: divorced	-0.352 ***
		(0.045)
fam_widowed	family status: widowed	-0.433 ***
		(0.061)
working_partner	patrner works (yes or no)	2.011 ***
		(0.031)
mortgage	one has a mortgage (yes or no)	-0.052 *
		(0.030)
car	one has a car (yes or no)	0.023
		(0.029)
Y2012	year dummy: 2012	0.048
		(0.035)
Y2013	year dummy: 2013	-0.012
		(0.036)
Y2014	year dummy: 2014	-0.046
		(0.036)
Y2015	year dummy: 2015	-0.052
		(0.037)
Y2016	year dummy: 2016	-0.061 *
		(0.037)
Constant		-23.925 ***
		(1.148)
Observations		89.611
Log Likelihood		-8,189.985
Chi squared		105,396.7 ***

*Note: Standard errors are in parentheses. * p < 0,10; ** p < 0,05; *** p < 0,01.*
Source: Calculations of the authors.

Appendix B: Calibration

In this appendix, we provide further details on the procedure of model parameters calibration. The process is mostly based on data from national accounts for the Czech economy. Our estimates are averaged for years 2011–2016 to avoid cyclical or one-off bias.

The Effective Tax Rate on Capital
We apply the methodology of Schmidt-Faber et al. (2004) for calculating the implicit tax rate on corporate income. The sectors of financial and nonfinancial corporations are involved:

$$\widehat{\tau_k} = \frac{\sum_{i\in\{11;12\}} D51_{S_i}}{D42r_{S13}+D42r_{S2}+\sum_{i\in\{11;12\}}\left(B2g_{S_i}+\Delta D41_{S_i}+\Delta D45_{S_i}+\Delta D42_{S_i}\right)} \tag{17}$$

where $D51$[7] are paid current taxes on income, $D42r$ are dividends received, $B2g$ is net operating surplus, $\Delta D41$ is a balance of interest (received minus paid), $\Delta D45$ is a balance of rent, $\Delta D42$ is a balance of dividends. S_i stands for a particular sector in a usual national-accounts notation.

From a taxation point of view, dividends are non-deductible part of corporate income, so we want to include only dividends paid between financial and non-financial corporations in the tax base. This adjustment is made by adding dividends received by government sector and non-residents as shown above.

The implicit tax rates on capital are then averaged, giving the value of 0.227. We find this method suitable for our model with a representative firm. Broader coverage of taxes on capital might be found in the literature. It includes personal income tax on self-employed or tax on capital stocks of the household which pull effective tax rate down due to their lower implicit tax rate, see Eugène et al. (2014). This gives an overall implicit tax rate on capital. European Commission (2018) reports an implicit tax rate on capital in the Czech economy at 17.9%.

The Effective Tax Rate on Consumption
We closely follow the approach of Carey and Tchilinguirian (2000). Expenditure is recorded at final prices thus we have to deduct taxes on products from denominator as well as wage expenditure in the government sector:

$$\widehat{\tau_C} = \frac{D21_{S13}}{P3_P+P3_{S13}-PW_{S13}-D21_{S13}} \tag{18}$$

where $D21$ are taxes on products, $P3_P$ is private final consumption expenditure, $P3_{S13}$ is government final consumption expenditure and PW_{S13} are compensations of government employees (more precisely employees attributed to a general government sector). The average value is 0.238, which is slightly higher than the standard statutory value added tax rate of 21%.

The Effective Tax Rate on Sales
This rate is calculated as total tax revenue $(D2 + D5 + D91)$ divided by nominal GDP. The average rate is 0.191.

The Parameter of Elasticity β
We use the value of -0.25 in line with Benczúr et al. (2012).

Net User Cost of Capital
The net user cost is the before-tax real capital rental adjusted for depreciation; see Creedy and Gemmell (2015). We adopt calculation of net return on capital (before tax) for nonfinancial corporations[8] as

$$i^* = \frac{B2g_{S11}}{\sum_{i=2}^{5} \Delta AFi_{S11}} \tag{19}$$

Where $B2g$ is net operating surplus and denominator consists of the difference in main financial items (liabilities minus assets) as noted in national accounts. The information on financial items is taken from the balance sheet for non-financial corporations at the beginning of the year.

Then we use the well-known Fischer equation with consumer price inflation rate

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[7] In this appendix we use a standardized notation from ESA 2010.

[8] The financial corporations follow a different pattern of return on capital. Our representative firm rather produces nonfinancial output as is usual in the Czech economy.

$$\hat{r} = \frac{i^{*}-\pi}{1+\pi}. \tag{20}$$

Finally, we combine our estimate of τ_k to calculate $\frac{r}{1-\tau_k}$. The average value is 0.202.

The Share of Capital α

The parameter α can be derived from first-order condition (derivative with respect to capital). We start from equation 31 in Appendix D

$$\alpha\left(\alpha K^{\beta} + (1-\alpha)L^{\beta}\right)^{\frac{1-\beta}{\beta}} K^{\beta-1} = \frac{r}{(1-\tau_k)(1-\tau_s)} \tag{21}$$

$$\alpha^{\frac{1}{1-\beta}}\left(\alpha K^{\beta} + (1-\alpha)L^{\beta}\right)^{\frac{1}{\beta}} K^{-1} = \left(\frac{r}{(1-\tau_k)(1-\tau_s)}\right)^{\frac{1}{1-\beta}}. \tag{22}$$

Since Y is equal to

$$Y = \left(\alpha K^{\beta} + (1-\alpha)L^{\beta}\right)^{\frac{1}{\beta}} \tag{23}$$

we can write

$$\alpha^{\frac{1}{1-\beta}} Y K^{-1} = \left(\frac{r}{(1-\tau_k)(1-\tau_s)}\right)^{\frac{1}{1-\beta}} \tag{24}$$

$$\alpha = \left(\frac{K}{Y}\right)^{1-\beta} \frac{r}{(1-\tau_k)(1-\tau_s)} \tag{25}$$

or equivalently

$$\alpha = \left(\frac{\frac{r}{(1-\tau_k)(1-\tau_s)}K}{Y}\right)^{1-\beta} \left(\frac{r}{(1-\tau_k)(1-\tau_s)}\right)^{\beta}. \tag{26}$$

Based on the previous calibration we obtain $\hat{\alpha} = 0.606$.

The Elasticity of Capital Supply

Variant specifications may be tested such as $\eta \approx 0$ or $\eta \to \infty$. We set up $\eta = 15$, which is consistent with a small and open Czech economy.

Non-accelerating Inflation Rate of Unemployment (NAIRU)

We estimate cohort-specific NAIRUs using a probit estimation of unemployment given very general personal characteristics. Benczúr et al. (2014) apply the same approach. The explanatory variables include education, age, the square of age, region, sex, year dummies, and interaction terms with age and education.

Table 9: Calibrated Parameters

Parameter	MF ČR (2020)	Benczúr et al. (2012)	Siebertová et al. (2015)
τ_K	0.23	0.07	0.12
τ_s	0.19	0.02	0.17
τ_C	0.24	0.18	0.14
β	-0.25	-0.25	-1.08
$r/(1-\tau_K)$	0.20	0.16	0.05
α	0.61	0.43	0.43
country	Czech Republic	Hungary	Slovakia
period	2011–2016	2005–2008	2010–2012

Source: Benczúr et al. (2012), Siebertová et al. (2015). Calculations of the authors.

Comparison with Other Studies

As a comparison, we report calibrated parameters from similar studies on Hungary and Slovakia in Table 9. We can see some discrepancy in calibration, especially for the effective tax rate on capital possibly due to the above-mentioned methodological issues. Simulation exercises prove the model to be insensitive to variant levels of τ_k (ceteris paribus).

On the other hand, discrepancies in parameters (such as α) may arise because of derived calculations. The basic sensitivity analysis is carried out in Section 4.

Appendix C: Considered Taxes and Benefits

The range of simulated tax allowances and benefits is briefly described in Table 10. The corresponding values are taken for each year separately. The description of the Czech tax-benefit system can be found in many papers; for instance, OECD offers useful policy summaries for different countries and years[9]. Old-age pensions are taken directly from data as a part of non-labour income; they are not simulated due to lack of relevant data. In the calculation of net income, employer's benefits in kind are included.

We do not consider mortgage interest payments and other less significant tax-deductible items due to lack of relevant data. All legally entitled benefits are assumed to be fully drawn which is reasonable for most types of benefits. These two ignored effects with countervailing impact might result in a slightly biased net income. The self-employed are taxed the same way as employees are and we treat the non-employed as potential employees. This simplification does not reflect actually different regimes in the taxation of self-employed in the Czech Republic.

Table 10: Modelled Features of the Czech Tax-benefit System

Item	Note
Taxes	
Base allowance	all taxpayers can apply
Spouse allowance	in case of legal spouse with low income
Child allowance	amount differs for the first, second and any other child
Income tax rate	15% of compensations
Social security contributions	11% in total payable by employee
Tax bonus	effectively negative tax for low incomers
Benefits	
Unemployment benefit	
Housing allowance	
Housing supplement	
Maternity benefit	
Parental allowance	not means-tested
Children benefit	for families with income ≤ 2.4 x living minimum
Assistance in material need	
Social supplement	only until 2011

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[9] http://www.oecd.org/els/benefits-and-wages.htm

Appendix D: Model derivations

Profit-maximizing Firm
The production function of the representative firm exhibits constant elasticity of substitution

$$Y = \left(\alpha K^{\beta} + (1-\alpha)L^{\beta}\right)^{1/\beta}. \tag{27}$$

Firms maximize profit

$$\left(\alpha K^{\beta} + (1-\alpha)L^{\beta}\right)^{1/\beta}(1-\tau_s) - w(1+\tau_w)L - \frac{r}{1-\tau_k}K \tag{28}$$

where τ_s is the effective tax rate on sales, w is the gross wage, τ_w is the employer-side social security contributions (payroll tax), τ_k is the effective tax rate on capital and $\frac{r}{1-\tau_k}$ is the net user cost of capital.

First-order Conditions

$$\frac{\partial\pi}{\partial K} = \frac{1}{\beta}\left(\alpha K^{\beta} + (1-\alpha)L^{\beta}\right)^{\frac{1}{\beta}-1}\beta\alpha K^{\beta-1}(1-\tau_s) - \frac{r}{1-\tau_k} = 0 \tag{29}$$

$$\left(\alpha K^{\beta} + (1-\alpha)L^{\beta}\right)^{\frac{1-\beta}{\beta}}\alpha K^{\beta-1}(1-\tau_s) - \frac{r}{1-\tau_k} = 0 \tag{30}$$

$$\left(\alpha K^{\beta} + (1-\alpha)L^{\beta}\right)^{\frac{1-\beta}{\beta}}K^{\beta-1} = \frac{r}{\alpha(1-\tau_k)(1-\tau_s)} \tag{31}$$

Now we take both sides of the equation to the power $\frac{\beta}{1-\beta}$:

$$\left(\alpha K^{\beta} + (1-\alpha)L^{\beta}\right)K^{-\beta} = \left(\frac{r}{\alpha(1-\tau_k)(1-\tau_s)}\right)^{\frac{\beta}{1-\beta}} \tag{32}$$

and denoting $\frac{K}{L} = k$:

$$\alpha + (1-\alpha)k^{-\beta} = \left(\frac{r}{\alpha(1-\tau_k)(1-\tau_s)}\right)^{\frac{\beta}{1-\beta}} \tag{33}$$

and reversing the previous step of taking to the power we now use $\frac{1-\beta}{\beta}$ to arrive at:

$$\left(\alpha + (1-\alpha)k^{-\beta}\right)^{\frac{1-\beta}{\beta}} = \frac{r}{\alpha(1-\tau_k)(1-\tau_s)} \tag{34}$$

Similarly:

$$\frac{\partial\pi}{\partial L} = \frac{1}{\beta}\left(\alpha K^{\beta} + (1-\alpha)L^{\beta}\right)^{\frac{1}{\beta}-1}\beta(1-\alpha)L^{\beta-1}(1-\tau_s) - w(1+\tau_w) = 0 \tag{35}$$

$$\left(\alpha K^{\beta} + (1-\alpha)L^{\beta}\right)^{\frac{1-\beta}{\beta}}(1-\alpha)L^{\beta-1}(1-\tau_s) - w(1+\tau_w) = 0 \tag{36}$$

$$\left(\alpha K^{\beta} + (1-\alpha)L^{\beta}\right)^{\frac{1-\beta}{\beta}}L^{\beta-1} = \frac{w(1+\tau_w)}{(1-\tau_s)(1-\alpha)} \tag{37}$$

Now we take both sides of the equation to the power $\frac{\beta}{1-\beta}$:

$$\left(\alpha K^{\beta} + (1-\alpha)L^{\beta}\right)L^{-\beta} = \left(\frac{w(1+\tau_w)}{(1-\tau_s)(1-\alpha)}\right)^{\frac{\beta}{1-\beta}} \tag{38}$$

$$\alpha k^{\beta} + (1-\alpha) = \left(\frac{w(1+\tau_w)}{(1-\tau_s)(1-\alpha)}\right)^{\frac{\beta}{1-\beta}} \tag{39}$$

and again reversing the previous step, we arrive at

$$\left(\alpha k^{\beta}+(1-\alpha)\right)^{\frac{1-\beta}{\beta}}=\frac{w(1+\tau_w)}{(1-\tau_s)(1-\alpha)} \tag{40}$$

Log-linearization
Taking the logarithm of the left-hand side of equation (34):

$$\log\left(\alpha+(1-\alpha)k^{-\beta}\right)^{\frac{1-\beta}{\beta}}=\frac{1-\beta}{\beta}\log\left(\alpha+(1-\alpha)k^{-\beta}\right) \tag{41}$$

and then using Taylor approximation

$$\frac{1-\beta}{\beta}\log\left(\alpha+(1-\alpha)k^{-\beta}\right)\approx\frac{1-\beta}{\beta}\frac{1}{\alpha+(1-\alpha)\bar{k}^{-\beta}}(1-\alpha)(-\beta)\bar{k}^{-\beta-1}\frac{k-\bar{k}}{\bar{k}}\bar{k}. \tag{42}$$

Using $\tilde{x}=\frac{x-\bar{x}}{\bar{x}}$ and rearranging:

$$-(1-\beta)\frac{1-\alpha}{\alpha+(1-\alpha)\bar{k}^{-\beta}}\bar{k}^{-\beta}\tilde{k}. \tag{43}$$

The logarithm of the right-hand side of (34) is $\log r-\log(1-\tau_k)-\log(1-\tau_s)-\log\alpha$ and is Taylor-approximated by

$$\frac{1}{\bar{r}}\left(\frac{r-\bar{r}}{\bar{r}}\right)\bar{r}-\frac{1}{\overline{(1-\tau_k)}}\left(\frac{(1-\tau_k)-\overline{(1-\tau_k)}}{\overline{(1-\tau_k)}}\right)\overline{(1-\tau_k)}-\frac{1}{\overline{(1-\tau_s)}}\left(\frac{(1-\tau_s)-\overline{(1-\tau_s)}}{\overline{(1-\tau_s)}}\right)\overline{(1-\tau_s)} \tag{44}$$

where $\log\alpha$ is missing since α is constant. Then (44) leads to

$$\tilde{r}-\widetilde{(1-\tau_k)}-\widetilde{(1-\tau_s)}. \tag{45}$$

Putting the left-hand side (43) equal to the right-hand side (45) gives

$$-(1-\beta)\frac{1-\alpha}{\alpha+(1-\alpha)\bar{k}^{-\beta}}\bar{k}^{-\beta}\tilde{k}=\tilde{r}-\widetilde{(1-\tau_k)}-\widetilde{(1-\tau_s)}. \tag{46}$$

Plugging steady states in (33) we get

$$-(1-\beta)\frac{1-\alpha}{\left(\frac{\bar{r}}{\alpha\overline{(1-\tau_k)}\,\overline{(1-\tau_s)}}\right)^{\frac{\beta}{1-\beta}}}\bar{k}^{-\beta}\tilde{k}=\tilde{r}-\widetilde{(1-\tau_k)}-\widetilde{(1-\tau_s)} \tag{47}$$

Rearranging:

$$-\alpha\tilde{k}=\frac{1}{-(1-\beta)\bar{k}^{-\beta}}\left(\frac{1}{\alpha}\right)^{\frac{\beta}{1-\beta}}\left(\frac{\bar{r}}{\overline{(1-\tau_k)}\,\overline{(1-\tau_s)}}\right)^{\frac{\beta}{1-\beta}}\left(\tilde{r}-\widetilde{(1-\tau_k)}-\widetilde{(1-\tau_s)}\right)-\tilde{k} \tag{48}$$

$$\tilde{k}=\frac{1}{(1-\beta)\bar{k}^{-\beta}}\left(\frac{1}{\alpha}\right)^{\frac{1}{1-\beta}}\left(\frac{\bar{r}}{\overline{(1-\tau_k)}\,\overline{(1-\tau_s)}}\right)^{\frac{\beta}{1-\beta}}\left(\tilde{r}-\widetilde{(1-\tau_k)}-\widetilde{(1-\tau_s)}\right)+\frac{1}{\alpha}\tilde{k} \tag{49}$$

Next, we log-linearize the first-order condition with respect to L. Taking the log of the left-hand side in (40) we arrive at $\frac{1-\beta}{\beta}\log\left(\alpha k^{\beta}+(1-\alpha)\right)$ and using Taylor approximation:

$$\frac{1-\beta}{\beta}\frac{\alpha\beta}{\alpha\bar{k}^{\beta}+(1-\alpha)}\bar{k}^{\beta-1}\frac{k-\bar{k}}{\bar{k}}\bar{k}. \tag{50}$$

Rearranging and substituting $\tilde{x}=\frac{x-\bar{x}}{\bar{x}}$ we get

$$\frac{(1-\beta)\alpha}{\alpha\bar{k}^{\beta}+(1-\alpha)}\bar{k}^{\beta}\tilde{k} \tag{51}$$

Taking the log of the right-hand side gives $\log w+\log(1+\tau_w)-\log(1-\tau_s)-\log(1-\alpha)$ and then

$$\frac{1}{\bar{w}}\left(\frac{w-\bar{w}}{\bar{w}}\right)\bar{w}+\frac{1}{\overline{(1+\tau_w)}}\left(\frac{(1+\tau_w)-\overline{(1+\tau_w)}}{\overline{(1+\tau_w)}}\right)\overline{(1+\tau_w)}-\frac{1}{\overline{(1-\tau_s)}}\left(\frac{(1-\tau_s)-\overline{(1-\tau_s)}}{\overline{(1-\tau_s)}}\right)\overline{(1-\tau_s)} \tag{52}$$

which leads to

$$\tilde{w}+\widetilde{(1+\tau_w)}-\widetilde{(1-\tau_s)} \tag{53}$$

Putting the left-hand side (51) equal to the right-hand side (53) gives

$$\frac{(1-\beta)\alpha}{\alpha\bar{k}^{\beta}+(1-\alpha)}\bar{k}^{\beta}\tilde{k} = \tilde{w} + \left(\widetilde{1+\tau_w}\right) - \left(\widetilde{1-\tau_s}\right) \tag{54}$$

Plugging steady states in (39) we get

$$\frac{(1-\beta)\alpha}{\left(\frac{w(1+\tau_w)}{(1-\tau_s)(1-\alpha)}\right)^{\frac{\beta}{1-\beta}}}\bar{k}^{\beta}\tilde{k} = \tilde{w} + \left(\widetilde{1+\tau_w}\right) - \left(\widetilde{1-\tau_s}\right) \tag{55}$$

and finally rearranging:

$$\tilde{k} = \frac{1}{\alpha\bar{k}^{\beta}}\left(\frac{1}{1-\alpha}\right)^{\frac{\beta}{1-\beta}}\frac{1}{1-\beta}\left(\frac{\bar{w}\overline{(1+\tau_w)}}{\overline{(1-\tau_s)}}\right)^{\frac{\beta}{1-\beta}}\left(\tilde{w} + \left(\widetilde{1+\tau_w}\right) - \left(\widetilde{1-\tau_s}\right)\right). \tag{56}$$

Regarding the deviation of output in (27):

$$\tilde{Y} = \frac{1}{\beta}\log\left(\alpha K^{\beta} + (1-\alpha)L^{\beta}\right) \tag{57}$$

$$= \left(\alpha\bar{K}^{\beta} + (1-\alpha)\bar{L}^{\beta}\right)^{-1}\alpha\bar{K}^{\beta-1}(K-\bar{K}) + \left(\alpha\bar{K}^{\beta} + (1-\alpha)\bar{L}^{\beta}\right)^{-1}(1-\alpha)\bar{L}^{\beta-1}(L-\bar{L}) \tag{58}$$

$$= \bar{K}^{-\beta}\left(\alpha + (1-\alpha)\bar{k}^{-\beta}\right)^{-1}\alpha\bar{K}^{\beta}\tilde{K} + \bar{L}^{-\beta}\left(\alpha\bar{k}^{\beta} + (1-\alpha)\right)^{-1}(1-\alpha)\bar{L}^{\beta}\tilde{L} \tag{59}$$

$$= \left(\frac{1-\alpha}{\alpha}\bar{k}^{-\beta} + 1\right)^{-1}\tilde{K} + \left(\frac{\alpha}{1-\alpha}\bar{k}^{\beta} + 1\right)^{-1}\tilde{L} \tag{60}$$

Closing the Model

We have two equations in a log-linearized form resulting from first-order conditions:

$$\tilde{k} = \frac{1}{(1-\beta)\bar{k}^{-\beta}}\left(\frac{1}{\alpha}\right)^{\frac{1}{1-\beta}}\left(\frac{\bar{r}}{\overline{(1-\tau_k)}\overline{(1-\tau_s)}}\right)^{\frac{\beta}{1-\beta}}\left(\tilde{r} - \left(\widetilde{1-\tau_k}\right) - \left(\widetilde{1-\tau_s}\right)\right) + \frac{1}{\alpha}\tilde{k}, \tag{61}$$

$$\tilde{k} = \frac{1}{\alpha\bar{k}^{\beta}}\left(\frac{1}{1-\alpha}\right)^{\frac{\beta}{1-\beta}}\frac{1}{1-\beta}\left(\frac{\bar{w}\overline{(1+\tau_w)}}{\overline{(1-\tau_s)}}\right)^{\frac{\beta}{1-\beta}}\left(\tilde{w} + \left(\widetilde{1+\tau_w}\right) - \left(\widetilde{1-\tau_s}\right)\right). \tag{62}$$

The model is closed by the equation that determines the aggregate supply of capital. Capital is provided by an international capital market. Its supply is modelled in a reduced form:

$$\tilde{K} = \eta\tilde{r} \tag{63}$$

Where η is the elasticity of capital supply K with respect to the after-tax rate of return r and

$$\tilde{k} = \tilde{K} - \tilde{L}. \tag{64}$$

Steady-states

From equations (33) and (40) we obtain

$$\bar{k} = \left(\frac{\left(\frac{\bar{r}}{\alpha(1-\overline{\tau_k})(1-\overline{\tau_s})}\right)^{\frac{\beta}{1-\beta}} - \alpha}{1-\alpha}\right)^{-\frac{1}{\beta}}, \tag{65}$$

$$\bar{w} = \left(\alpha\bar{k}^{\beta} + (1-\alpha)\right)^{\frac{1-\beta}{\beta}}\frac{(1-\overline{\tau_s})(1-\alpha)}{1+\overline{\tau_w}}. \tag{66}$$

Solution

$$\tilde{k}(\alpha-1) = \frac{1}{(1-\beta)\bar{k}^{-\beta}}\left(\frac{1}{\alpha}\right)^{\frac{\beta}{1-\beta}}\left(\frac{\bar{r}}{(1-\overline{\tau_k})(1-\overline{\tau_s})}\right)^{\frac{\beta}{1-\beta}}\left(\tilde{r} - \left(\widetilde{1-\tau_k}\right) - \left(\widetilde{1-\tau_s}\right)\right) \tag{67}$$

We set

$$A2 = \frac{1}{(1-\beta)\bar{k}^{-\beta}}\left(\frac{1}{\alpha}\right)^{\frac{\beta}{1-\beta}}\left(\frac{\bar{r}}{(1-\overline{\tau_k})(1-\overline{\tau_s})}\right)^{\frac{\beta}{1-\beta}} \tag{68}$$

and use $\tilde{k} = \eta\tilde{r} - \tilde{L}$:

$$(\eta\tilde{r} - \tilde{L})(\alpha - 1) = A2\left(\tilde{r} - \left(\widetilde{1-\tau_k}\right) - \left(\widetilde{1-\tau_s}\right)\right), \tag{69}$$

$$\tilde{r} = \frac{1-\alpha}{(1-\alpha)\eta + A2}\tilde{L} + \frac{A2}{(1-\alpha)\eta + A2}\left(\left(\widetilde{1-\tau_k}\right) + \left(\widetilde{1-\tau_s}\right)\right). \tag{70}$$

Plugging back in $\tilde{k} = \eta\tilde{r} - \tilde{L}$:

$$\tilde{k} = \eta\left[\frac{1-\alpha}{(1-\alpha)\eta + A2}\tilde{L} + \frac{A2}{(1-\alpha)\eta + A2}\left(\left(\widetilde{1-\tau_k}\right) + \left(\widetilde{1-\tau_s}\right)\right)\right] - \tilde{L} \tag{71}$$

$$\tilde{k} = \frac{-A2}{(1-\alpha)\eta + A2}\tilde{L} + \frac{\eta A2}{(1-\alpha)\eta + A2}\left(\left(\widetilde{1-\tau_k}\right) + \left(\widetilde{1-\tau_s}\right)\right) \tag{72}$$

finally expressing $\widetilde{w}$:

$$\widetilde{w} = \frac{\tilde{k}}{\frac{1}{\alpha\bar{k}^{\beta}}\left(\frac{1}{1-\alpha}\right)^{\frac{\beta}{1-\beta}}\frac{1}{1-\beta}\left(\frac{\overline{w}(1+\overline{\tau_W})}{(1-\overline{\tau_S})}\right)^{\frac{\beta}{1-\beta}}} - \left(\widetilde{1+\tau_w}\right) + \left(\widetilde{1-\tau_s}\right) \tag{73}$$

setting

$$A1 = \frac{1}{\alpha\bar{k}^{\beta}}\left(\frac{1}{1-\alpha}\right)^{\frac{\beta}{1-\beta}}\frac{1}{1-\beta}\left(\frac{\overline{w}(1+\overline{\tau_W})}{(1-\overline{\tau_S})}\right)^{\frac{\beta}{1-\beta}} \tag{74}$$

and plugging (72):

$$\widetilde{w} = \frac{\frac{-A2}{(1-\alpha)\eta + A2}\tilde{L} + \frac{\eta A2}{(1-\alpha)\eta + A2}\left(\left(\widetilde{1-\tau_k}\right) + \left(\widetilde{1-\tau_s}\right)\right)}{A1} - \left(\widetilde{1+\tau_w}\right) + \left(\widetilde{1-\tau_s}\right) \tag{75}$$

$$\widetilde{w} = \frac{1}{\frac{A1(1-\alpha)\eta}{-A2} - A1}\tilde{L} - \frac{\eta}{\frac{A1(1-\alpha)\eta}{-A2} - A1}\left(\widetilde{1-\tau_k}\right) - \left(\frac{\eta}{\frac{A1(1-\alpha)\eta}{-A2} - A1} - 1\right)\left(\widetilde{1-\tau_s}\right) - \left(\widetilde{1+\tau_w}\right) \tag{76}$$

where $\tilde{L}$ is a labour supply shock resulting from the microsimulation model.

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