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Social Comparisons and Optimal Taxation in a Small Open Economy*

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Abstract

Almost all previous studies on optimal taxation and status consumption are based on closed model-economies. This paper analyzes how international capital mobility – which may constrain the use of capital income taxation – affects the optimal redistributive income tax policy in a small open economy when consumers care about their relative consumption. If the government can perfectly observe (and tax) returns on savings abroad, it is shown that the policy rules for marginal labor and capital income taxation derived for a closed economy largely carry over to the small open economy analyzed here. However, if these returns are unobserved by the government, the marginal tax policy rules will be very different from those pertaining to closed model-economies. In this case, capital income taxes on domestic savings will be completely ineffective, since such taxes would induce the consumers to move their savings abroad. The labor income tax must then indirectly also reflect the corrective purpose that the absent capital income tax would otherwise have had.

Keywords: Optimal taxation, relative consumption, positional goods, capital mobility, small open economy.

JEL Classification: D03, D60, D62, F21, H21, H23

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1. Introduction

People care about their relative consumption, i.e., how much they consume relative to other people's consumption.[1] While this insight has a long history, and was noted already by the founding fathers of economics including Adam Smith and John Stuart Mill, the literature dealing with optimal tax policy implications of relative consumption comparisons is more recent. A major finding in this literature is that such comparisons imply much higher optimal marginal income tax rates than in standard economic models, due to that concerns for relative consumption give rise to large negative externalities (often referred to as positional externalities). It also explains how this corrective tax element is modified when information asymmetries prevent redistribution through lump-sum taxes.[2]

Most earlier studies dealing with tax policy implications of social comparisons are based on static models, and thus do not address the potential role of *capital* income taxation. This omission is important, since relative consumption concerns give rise to a corrective as well as redistributive motive for using capital income taxation. To our knowledge, Aronsson and Johansson-Stenman (2010) was the first paper to analyze the role of capital income taxation in an economy where people care about relative consumption, and where the government can simultaneously use an optimal nonlinear labor income tax for purposes of redistribution and externality correction.[3] They found that consumer preferences for relative consumption have important implications for capital income taxation even if the labor income tax is optimal, since the positional externalities that consumers impose on one another may vary over the individual life-cycle as well as vary over time in general. The more (less) positional people become over time, the stronger will typically be the argument for taxing (subsidizing) savings at the margin. For instance, if people become more positional when their income increases, as suggested by empirical evidence in Clark et al. (2008), there would be an incentive to tax capital income at the margin in a growing economy where people become more positional over time. Similarly, if the young are more positional than the old, which is consistent with

[1] For empirical evidence from happiness and questionnaire-experimental research, see, e.g., Easterlin (1995, 2001), Johansson-Stenman et al., (2002), Blanchflower and Oswald (2005), Ferrer-i-Carbonell (2005), Solnick and Hemenway (2005), Carlsson et al. (2007), and Clark and Senik, 2010).

[2] The earlier literature in this area includes Boskin and Sheshinski (1978), Oswald (1983), Tuomala (1990), Ljunqvist and Uhlig (2000), Dupor and Liu (2003), Aronsson and Johansson-Stenman (2008), and Eckerstorfer and Wendner (2013).

[3] See also Aronsson and Johansson-Stenman (2014a) for a generalization, in particular with respect to the nature of the social comparisons. See Abel (2005) for a study of first best optimal capital income taxation in a representative-agent economy (without any labor income tax), where the representative consumer has preferences for relative consumption.

some empirical evidence (Pingle and Mitchell, 2002; Johansson-Stenman and Martinsson, 2006), it is for this reason desirable to subsidize capital income at the margin.

However, the studies on optimal taxation referred to above, and indeed almost all previous studies in the policy-oriented literature on relative consumption, are based on closed model-economies.[4] This is problematic when dealing with capital taxation since most (if not all) developed countries are open to capital mobility. The main contribution of the present paper is to generalize the setting of Aronsson and Johansson-Stenman (2010) to a small open economy with capital mobility, in which individuals may either invest their savings domestically or abroad. This generalization is clearly important because capital mobility may seriously restrict the use of capital income taxation as a means of correction and redistribution.

The point of departure is the optimal income tax model with overlapping generations (OLG) developed by Aronsson and Johansson-Stenman (2010), where (realistic) information asymmetries prevent the government from using type specific lump-sum taxes for purposes of redistribution. This model is here augmented with an international capital market and embedded into the framework of a small open economy.[5] A small open economy is here meant to imply that the country is small enough for its government to treat the world market interest rate as exogenous; a realistic assumption for many (if not most) countries. We will, nevertheless, comment on how the results would change if the economy is large in the sense that the government is able to (strategically) affect the world market interest rate.

The scope for capital income taxation will, of course, depend on whether all capital income is observable to the government. Following the notational convention in the literature on capital income taxation in open economies, we will refer to *source-based* capital income taxation when the capital income is taxed at source, i.e., imposed by the country where this income is generated, irrespective of whether the income earner is a domestic or foreign resident. *Residence-based* capital income taxation in contrast means that the tax is levied on the citizens of a particular country irrespective of whether they earn their income at domestically or abroad. An individual who lives in, say, the UK and who saves domestically will then be taxed by the UK government for the savings returns based on both the sourced-based tax (since the savings are undertaken in the UK) and the residence-based tax (since the

[4] To our knowledge, the only exceptions are Aronsson and Johansson-Stenman (2014b, 2015): the former examines the optimal provision of public goods and the latter deals with optimal income taxation in multi-country economies with social comparisons within as well as between countries.

[5] Many earlier studies have examined the implications of international capital mobility for revenue collection and provision of public goods at the national level in contexts without relative consumption comparisons; see, e.g., Zodrow and Mieszkowski (1986), Wilson (1986), Bucovetsky and Wilson (1991), and Huber (1999). See also Aronsson and Sjögren (2014), who analyze tax policy implications of quasi-hyperbolic discounting in an economy with international capital mobility.

saving is done by a UK citizen). If the same individual instead saves in Switzerland, then the UK government will only tax him/her through the residence-based tax, while the Swiss government may tax him/her through the source-based tax in Switzerland.

We will throughout the paper assume that the government can perfectly observe, and hence tax, the returns on capital within its own country; hence, it can impose source-based taxes without restrictions. Yet, we also assume, as is commonly done in the literature, that capital is perfectly mobile between countries while people are immobile,[6] and that the governments in different countries do not coordinate their capital tax policies. The possibility to observe the returns on savings abroad, and hence to implement residence-based capital income taxation, is much less obvious in practice. We will analyze the two extreme cases where such returns can either be observed perfectly or not observed at all. If the government can perfectly observe the returns on savings abroad, and can thus use a flexible nonlinear residence-based capital income tax, it is shown in Section 3 that the optimal tax policy rules derived for a closed economy by Aronsson and Johansson-Stenman (2010) largely carry over to the small open economy analyzed here. In addition it is shown that there would be no role for a source-based capital income tax since such a tax would induce people to move their savings abroad to escape this part of the capital tax (other small open economies would for the same reason have no source-based taxes). If, on the other hand, the government cannot observe (and tax) the returns on savings abroad, the tax policy rules will be dramatically different, as shown in Section 4. Yet, here too, the source-based capital income tax will be completely ineffective for the same reason as above. Instead, the labor income tax must indirectly, and imperfectly, reflect also the corrective purpose that the absent capital income tax would otherwise have had.

Although one may question the extreme case where the residence-based capital tax instrument cannot be used at all, it is arguably realistic that such a tax instrument cannot be used to its full potential. This would require a perfect international information sharing system where all relevant source-countries assist the domestic government in the collection of revenue.[7] And as long as residence-based capital income taxation cannot be fully used, the mechanisms derived for the extreme case without any possibility to use residence-based

[6] None of these assumptions are of course strictly fulfilled in reality; there are still some transaction costs associated with international capital mobility, and people do move between countries. Yet, capital is for sure considerably more mobile than people.

[7] See also Baccetta and Espinosa (1995) and Eggert and Kolmar (2002), who have studied this information-exchange problem.

taxation will still be relevant, i.e., what matters is that the government is forced into a corner solution for the residence-based tax.

The basic structure of the model is presented in Section 2, while the optimal tax policy with and without the possibility of using residence-based capital income taxation is addressed in Sections 3 and 4, respectively. Section 5 provides some concluding remarks.

2. The Model

Following Aronsson and Johansson-Stenman (2010), we consider an OLG economy and assume that each individual lives for two periods; works in the first and is retired in the second. Individuals are of two types, where the low-ability type (type 1) is less productive in the labor market - and consequently earns a lower before-tax wage rate - than the high-ability type (type 2). Those entering the economy in period *t* (who are active in the labor market in period *t* and retired in period *t*+1) will be referred to as generation *t*; $n_{i,t}$ will similarly denote the number of individuals of ability-type *i* (for *i*=1,2) in generation *t*.

2.1 Individual Preferences, Constraints, and Choices

An individual derives utility from his/her absolute consumption when young, $c_{i,t}$, and old, $x_{i,t+1}$, and use of leisure when young, $z_{i,t} = 1 - l_{i,t}$, where l denotes work hours and the time endowment has been normalized to one. The utility also depends on the individual's relative consumption when young and old.[8] We model relative consumption as the difference between the individual's own consumption and a measure of reference consumption. Using a bar symbol for reference consumption, we can then express the relative consumption of an individual of type *i* who is young in period *t* as $\Delta_{i,t}^{c} = c_{i,t} - \bar{c}_t$. The relative consumption of the same individual when old can similarly be written as $\Delta_{i,t+1}^{x} = x_{i,t+1} - \bar{c}_{t+1}$. We will throughout the paper follow convention in assuming that the reference consumption in each time period can be defined as the average consumption in the economy as a whole, such that

$$\bar{c}_t = \frac{n_{1,t}c_{1,t} + n_{2,t}c_{2,t} + n_{1,t-1}x_{1,t} + n_{2,t-1}x_{2,t}}{N_t}, \qquad (1)$$

[8] The limited empirical evidence available suggests that individuals are much less positional in terms of leisure than in terms of visible consumption goods, such as houses and cars, and income (Alpizar et al., 2005; Solnick and Hemenway, 2005; Carlsson et al., 2007).

in which $N_t = n_{1,t} + n_{2,t} + n_{1,t-1} + n_{2,t-1}$ denotes the total population in period *t*. The life-time utility function facing any individual of ability-type *i* and generation *t* can then be written as

$$U_{i,t} = u_{i,t}\left(c_{i,t}, z_{i,t}, x_{i,t+1}, \Delta_{i,t}^{c}, \Delta_{i,t+1}^{x}\right). \qquad (2)$$

This utility function is assumed to be increasing in each argument and strictly quasi-concave.

We follow Johansson-Stenman et al. (2002) and define the *degree of positionality* as a measure of the extent to which the marginal utility of consumption is driven by concerns for relative consumption. Since each individual lives for two periods, we can distinguish between the degree of positionality when young and when old. For any individual of ability-type *i* and generation *t*, these two measures can be written as

$$\alpha_{i,t}^{c} = \frac{\partial u_{i,t}/\partial \Delta_{i,t}^{c}}{\partial u_{i,t}/\partial c_{i,t} + \partial u_{i,t}/\partial \Delta_{i,t}^{c}} \quad \text{and} \quad \alpha_{i,t+1}^{x} = \frac{\partial u_{i,t}/\partial \Delta_{i,t+1}^{x}}{\partial u_{i,t}/\partial x_{i,t+1} + \partial u_{i,t}/\partial \Delta_{i,t+1}^{x}}. \qquad (3)$$

$\alpha_{i,t}^{c}$ is interpretable as the fraction of the utility gain of an additional dollar spent on consumption that is due to increased relative consumption when young in period *t*. In the extreme case where $\alpha_{i,t}^{c}$ approaches one, all that matters is relative consumption (i.e., the marginal utility of absolute consumption is zero), whereas the mirror case where $\alpha_{i,t}^{c}$ approaches zero reflects the conventional assumption where relative consumption does not matter at all. $\alpha_{i,t+1}^{x}$ has an analogous interpretation when old in period t+1.

Each individual has the option of investing his/her savings at home or abroad. Let $\bar{r}_t^n$ denote the foreign rate of return before any residence-based capital income tax (although after source-based taxation). The after-tax rate of return of a domestic investment is given by $r_{i,t}^{n} = (1 - \theta_{i,t}^{r})(1 - \theta_t^{s})r_t$, where $\theta_{i,t}^{r}$ denotes the residence-based marginal capital income tax rate facing ability-type *i*, θ_t^{s} denotes the source-based tax rate, r_t denotes the domestic before-tax interest rate, and the total marginal capital income tax rate can be calculated as $\theta_{i,t} = \theta_{i,t}^{r} + \theta_t^{s} - \theta_{i,t}^{r}\theta_t^{s}$.[9] Note that all individuals face the same source-based tax rate.[10] We assume that capital is perfectly mobile, which means that the following equilibrium condition applies (since the residence-based rate cancels out on both sides):

[9] This is based on Aronsson and Sjögren (2014). Another formulation would be to assume $\theta_{i,t} = \theta_{i,t}^{r} + \theta_t^{s}$. This formulation is more restrictive, since equation (4) then implies $\theta_{1,t} = \theta_{2,t}$, in which case the government does not have a fully flexible capital income tax.

[10] It would be very difficult for the government to differentiate the source based tax rate among the different consumer types since those facing the higher rate would invest their savings abroad instead of at home.

$$\bar{r}_t^n = (1-\theta_t^s)r_t. \tag{4}$$

Let $\tau_{i,t}$ denote the marginal labor income tax rate, $w_{i,t}$ the before-tax wage, $w_{i,t}^n = (1-\tau_{i,t})w_{i,t}$ the after-tax marginal wage rate and $s_{i,t}$ saving. The budget constraint facing any individual of ability-type *i* and generation *t* can then be summarized by the following two equations:[11]

$$c_{i,t} = w_{i,t}^n l_{i,t} - T_{i,t} - s_{i,t} \tag{5a}$$

$$x_{i,t+1} = s_{i,t}(1 + r_{i,t+1}^n) - \Phi_{i,t+1} \tag{5b}$$

where $T_{i,t}$ and $\Phi_{i,t+1}$ are lump-sum components of the tax system.[12] Each individual acts as an atomistic agent and treats the factor prices, tax variables (marginal tax rates and lump-sum components), and the measures of reference consumption as exogenous. The individual first-order conditions for work hours and saving can then be written as

$$\frac{\partial U_{i,t}}{\partial c_{i,t}} w_{i,t}^n - \frac{\partial U_{i,t}}{\partial z_{i,t}} = 0 \tag{6a}$$

$$\frac{\partial U_{i,t}}{\partial x_{i,t+1}}(1 + r_{i,t+1}^n) - \frac{\partial U_{i,t}}{\partial c_{i,t}} = 0 \tag{6b}$$

where $\partial U_{i,t}/\partial c_{i,t} = \partial u_{i,t}/\partial c_{i,t} + \partial u_{i,t}/\partial \Delta_{i,t}^c$ and $\partial U_{i,t}/\partial x_{i,t+1} = \partial u_{i,t}/\partial x_{i,t+1} + \partial u_{i,t}/\partial \Delta_{i,t+1}^x$. Equations (5) and (6) implicitly define the following labor supply and savings functions:

$$l_{i,t} = l_{i,t}(w_{i,t}^n, r_{i,t+1}^n, T_{i,t}, \Phi_{i,t+1}, \bar{c}_t, \bar{c}_{t+1}) \tag{7a}$$

$$s_{i,t} = s_{i,t}(w_{i,t}^n, r_{i,t+1}^n, T_{i,t}, \Phi_{i,t+1}, \bar{c}_t, \bar{c}_{t+1}) \tag{7b}$$

for *i*=1,2.

2.2 Production and Equilibrium

We assume that the production technology is characterized by constant returns to scale. Identical, competitive firms produce a homogenous good, and we normalize their number to

[11] This way of formulating the budget constraint with optimal nonlinear income taxes is chosen for analytical convenience. It is equivalent to a formulation where both types in each time period face the same general, nonlinear labor income and capital income taxation tax functions; see e.g. Aronsson and Johansson-Stenman (2010, 2014a).

[12] One way to interpret these lump-sum components is in terms of intercepts of locally linearized budget constraints, i.e., adjustments due to that inframarginal units of income are not taxed at the marginal rates.

one for notational convenience. Let $F(L_t, K_t)$ be the production function, where L_t denotes effective labor and K_t the capital stock used in the domestic production. In turn, effective labor is given by $L_t = a_1 L_{1,t} + a_2 L_{2,t}$, where $0 < a_1 < a_2$ are fixed parameters, while $L_{i,t} = n_{i,t} l_{i,t}$ denotes the total number of work hours by type *i* in period *t*. The necessary conditions equate marginal products and factor prices such that

$$a_1 \frac{\partial F_t}{\partial L_t} - w_{1,t} = 0, \qquad a_2 \frac{\partial F_t}{\partial L_t} - w_{2,t} = 0, \qquad \frac{\partial F_t}{\partial K_t} - r_t = 0. \tag{8}$$

Finally, let Q_t denote the part of the aggregate savings invested abroad in period *t*. It follows from the national accounts that

$$K_t + Q_t = \sum_{i=1,2} n_{i,t-1} s_{i,t-1}. \tag{9}$$

By combining equations (4), (8), and (9), and then using the measure of aggregate labor input $L_{i,t} = n_{i,t} l_{i,t}$ for *i*=1,2, we can derive an equation system that implicitly defines $w_{1,t}$, $w_{2,t}$, r_t, K_t, and Q_t as functions of θ_t, $l_{1,t}$, $l_{2,t}$, $s_{1,t-1}$, and $s_{2,t-1}$, i.e.,

$$w_{i,t} = w_{i,t}(\theta_t, l_{1,t}, l_{2,t}, s_{1,t-1}, s_{2,t-1}) \quad \text{for } i=1,2 \tag{10a}$$

$$r_t = r_t(\theta_t, l_{1,t}, l_{2,t}, s_{1,t-1}, s_{2,t-1}) \tag{10b}$$

$$K_t = K_t(\theta_t, l_{1,t}, l_{2,t}, s_{1,t-1}, s_{2,t-1}) \tag{10c}$$

$$Q_t = Q_t(\theta_t, l_{1,t}, l_{2,t}, s_{1,t-1}, s_{2,t-1}) \tag{10d}$$

where $l_{1,t}$, $l_{2,t}$, $s_{1,t-1}$, and $s_{2,t-1}$ are defined in equations (7a) and (7b), while population variables (the number of individuals of each type) have been suppressed to avoid unnecessary notation.

2.3 The Government and Optimal Taxation

The social objective function is assumed to be Utilitarian

$$W = \sum_{t=0}^{\infty} \sum_{i=1,2} n_{i,t} U_{i,t}. \tag{11}$$

This specific functional form simplifies the calculations. It is not important for the efficiency conditions presented below. Indeed, the qualitative results would continue to hold for any social objective function that is increasing in the utility of each type in each time period. They would also continue to hold when the social objective is to obtain a Pareto efficient allocation, i.e. when the utility of a specific type in a specific time period is maximized, while utility of the other type in the same time period, as well as the utility of both types in all other time periods, are held fixed.

The government is assumed to observe the labor and capital income at the individual level, whereas individual ability is private information. We also (and quite realistically) assume that the government wants to redistribute from the high-ability to the low-ability type. To eliminate the incentive for high-ability individuals to mimic the low-ability type in order to gain from this redistribution, the following self-selection constraint will be imposed:

$$U_{2,t} = u_{2,t}\left(c_{2,t}, z_{2,t}, x_{2,t+1}, \Delta_{2,t}^{c}, \Delta_{2,t+1}^{x}\right) \geq \hat{u}_{2,t}\left(c_{1,t}, \hat{z}_{2,t}, x_{1,t+1}, \Delta_{1,t}^{c}, \Delta_{1,t+1}^{x}\right) = \widehat{U}_{2,t}. \quad (12)$$

The left hand side of the weak inequality (12) is the utility of the true high-ability type, and the right hand side the utility of the mimicker. A mimicker earns the same labor and capital income, and consumes as much in both periods, as the low-ability type. The variable $\hat{z}_{2,t} = 1 - \phi l_{1,t}$ denotes the time spent on leisure by the mimicker: since the mimicker is more productive than the low-ability type, we have $\hat{z}_{2,t} = 1 - \phi l_{1,t} > z_{1,t}$.

With a full set of tax instruments, and by using $\tau_{i,t} w_{i,t} = w_{i,t} - w_{i,t}^{n}$ and $\theta_{i,t} r_t = r_t - r_{i,t}^{n}$, the public budget constraint can be written as

$$0 = \sum_{i=1,2} n_{i,t}\left[\left(w_{i,t} - w_{i,t}^{n}\right) l_{i,t} + T_{i,t}\right] + \sum_{i=1,2} n_{i,t-1}\left[\Phi_{i,t} + \left(r_t - r_{i,t}^{n}\right) s_{i,t-1}\right] - \theta_t^{s} r_t Q_t. \quad (13)$$

Equation (13) abstracts from public expenditure on public and private goods, which are of no concern in the analysis to follow.

The public decision-problem is then to choose the policy vector $\left(\theta_t^{s}, w_{i,t}^{n}, r_{i,t}^{n}, T_{i,t}, \Phi_{i,t+1}\right)$ for i=1,2 and all t to maximize the social welfare function given in equation (11) subject to the self-selection and budget constraints in equations (12) and (13), as well as subject to the private sector optimality and equilibrium conditions given in equations (7), (8), and (10). The Lagrangean can then be written as follows:

$$\mathcal{L} = \sum_{t=0}^{\infty} \sum_{i=1,2} n_{i,t} U_{i,t} + \sum_{t=0}^{\infty} \lambda_t \left(U_{2,t} - \widehat{U}_{2,t}\right) + \sum_{t=0}^{\infty} \mu_t \left(\bar{c}_t - \sum_{i=1,2} \frac{\left(n_{i,t} c_{i,t} + n_{i,t-1} x_{i,t}\right)}{N_t}\right)$$
$$+ \sum_{t=0}^{\infty} \gamma_t \left[\sum_{i=1,2} n_{i,t}\left[\left(w_{i,t} - w_{i,t}^{n}\right) l_{i,t} + T_{i,t}\right] + \sum_{i=1,2} n_{i,t-1}\left[\Phi_{i,t} + \left(r_t - r_{i,t}^{n}\right) s_{i,t-1}\right] - \theta_t^{s} r_t Q_t\right]$$

where λ_t and γ_t are the Lagrange multipliers associated with the self-selection constraint and the budget constraint in period t, respectively. The government attempts to redistribute and internalize the positional externality that the relative consumption concerns give rise to. Note that we have included equation (1) – which shows how the reference consumption is determined - as an explicit constraint, and μ_t denotes the associated Lagrange multiplier.

3. Optimal Tax Policy under Residence-Based Capital Income Taxes

We begin by discussing the second best optimal marginal tax structure, which solves the optimal tax problem described above where the government has a full set of tax instruments, and continue in Section 4 with a restricted optimal tax problem without the residence-based capital income tax. Let

$$\bar{\alpha}_t = \sum_{i=1,2} \alpha_{i,t}^{x} \frac{n_{i,t-1}}{N_t} + \sum_{i=1,2} \alpha_{i,t}^{c} \frac{n_{i,t}}{N_t}$$

denote the average degree of positionality measured among those alive in period *t*. Since all individuals compare their own consumption with the average consumption, we can interpret the average degree of positionality as measuring the value of the marginal consumption externality per unit of consumption.[13] Also, let $\hat{\alpha}_{2,t}^{c}$ and $\hat{\alpha}_{2,t+1}^{x}$ denote the degree of positionality of the young and old mimicker, respectively, of generation *t*, which are calculated as in equations (3) although based on the mimicker's utility function.

The social shadow price of reference consumption, μ_t, plays an important role in the tax policy described below. This shadow price reflects the welfare effect of a decrease in $\bar{c}_t$, ceteris paribus, and is given as follows at the second best optimum:

$$\mu_t = N_t \gamma_t \frac{\bar{\alpha}_t}{1-\bar{\alpha}_t} - \frac{1}{(1-\bar{\alpha}_t)} \left[\lambda_{t-1} \frac{\partial \hat{U}_{2,t-1}}{\partial x_{1,t}} \left(\hat{\alpha}_{2,t}^{x} - \alpha_{1,t}^{x} \right) + \lambda_t \frac{\partial \hat{U}_{2,t}}{\partial c_{1,t}} \left(\hat{\alpha}_{2,t}^{c} - \alpha_{1,t}^{c} \right) \right] \quad (14)$$

Equation (14) takes the same form as the corresponding shadow price derived for a closed economy by Aronsson and Johansson-Stenman (2010). The first term on the right hand side reflects the efficiency cost of the positional consumption externality and depends on the average degree of positionality. The intuition is that the larger the positional externality, the greater will be the welfare benefit of a decrease in $\bar{c}_t$, which explains why this component works to increase the shadow price (i.e., making it more desirable to reduce $\bar{c}_t$ from the

[13] Empirical literature has repeatedly found the average degree of positionality to be quite large both for income (which can be seen as a summary measure of consumption in general) as well as for clearly visible goods such as houses and cars. For instance, Alpizar et al. (2005) and Carlsson et al. (2007) find an estimate of around 0.4-0.5, whereas the literature review by Wendner and Goulder (2008) argues in favor of a slightly lower interval, 0.2-0.4. This suggests that positional externalities are associated with large welfare costs; see also Frank (2005).

perspective of the government). Yet, this is not the whole story as can seen from the second term, which depends on differences in the degree of positionality between the mimicker and the low-ability type. If the low-ability type is more positional than the mimicker both when young and old, this effect also works to increase μ_t since a decrease in $\bar{c}_t$ will in that case lead to a relaxation of the self-selection constraint (in addition to the pure efficiency gain of a smaller externality). However, if the mimicker is more positional than the low-ability type, such that the expression in square brackets is positive, increased reference consumption instead contributes to a relaxation of the self-selection constraint. In turn, this means that the second term in (14) is negative and contributes to reduce μ_t. As such, in a second best world with information asymmetries, we cannot *a priori* rule out that an increase in $\bar{c}_t$ leads to higher welfare (even if this scenario does not appear very likely to us).

With equation (14) at our disposal, it is straight forward to show that the model set out above produces results analogous to those derived for a closed economy by Aronsson and Johansson-Stenman (2010). Let $MRS_{i,t}^{z,c} = (\partial U_{i,t}/\partial z_{i,t})/(\partial U_{i,t}/\partial c_{i,t})$ denote the marginal rate of substitution between leisure and private consumption and $MRS_{i,t}^{c,x} = (\partial U_{i,t}/\partial c_{i,t})/(\partial U_{i,t}/\partial x_{i,t+1})$ denote the marginal rate of substitution between present and future consumption for ability-type *i* of generation *t*, while $\widehat{MRS}_{2,t}^{z,c}$ and $\widehat{MRS}_{2,t}^{c,x}$ denote the corresponding marginal rates of substitution for the mimicker. We will summarize the optimal tax policy in terms of the following proposition:

Proposition 1. *The optimal second best policy based on a full set of instruments satisfies* $\theta_i^s = 0$ *in combination with the following marginal labor income tax rates:*

$$\tau_{1,t} = \frac{\lambda_t^*}{w_{1,t}n_{1,t}}\left(MRS_{1,t}^{z,c} - \phi\widehat{MRS}_{2,t}^{z,c}\right) + \frac{MRS_{1,t}^{z,c}}{w_{1,t}N_t}\frac{\mu_t}{\gamma_t} \quad (15a)$$

$$\tau_{2,t} = \frac{MRS_{2,t}^{z,c}}{w_{2,t}N_t}\frac{\mu_t}{\gamma_t} \quad (15b)$$

where $\lambda_t^* = \lambda_t\left(\partial\hat{U}_{2,t}/\partial c_{1,t}\right)/\gamma_t$*, and the following marginal capital income tax rates:*

$$\theta_{1,t+1} = \frac{\lambda_t\left(\partial\hat{U}_{2,t}/\partial x_{1,t+1}\right)}{\gamma_{t+1}r_{t+1}n_{1,t}}\left(MRS_{1,t}^{c,x} - \widehat{MRS}_{2,t}^{c,x}\right) - \frac{1}{\gamma_{t+1}r_{t+1}}\left(\frac{\mu_t}{N_t} - MRS_{1,t}^{c,x}\frac{\mu_{t+1}}{N_{t+1}}\right) \quad (16a)$$

$$\theta_{2,t+1} = -\frac{1}{\gamma_{t+1}r_{t+1}}\left(\frac{\mu_t}{N_t} - MRS_{2,t}^{c,x}\frac{\mu_{t+1}}{N_{t+1}}\right) \quad (16b)$$

for all t.

Proof: see the Appendix.

The intuition as to why the source-based capital income tax rate is zero is that capital is perfectly mobile in to, and out of, the country: therefore, since the government of the small open economy treats the world market interest rate as exogenous, it will not use the source-based tax. The marginal capital income tax rates implemented by the government in equations (16a) and (16b) thus coincide with the residence-based marginal tax rates, i.e., $\theta_{1,t+1} = \theta^r_{1,t+1}$ and $\theta_{2,t+1} = \theta^r_{2,t+1}$.

Equations (15a), (15b), (16a), and (16b) take the same form as their counterparts derived for a closed economy by Aronsson and Johansson-Stenman (2010), and the interpretations are the same as in their study. It is, nevertheless, worthwhile to discuss the insights from the proposition, since these insights will useful in the analysis to follow. The first term on the right hand side of equations (15a) and (16a), respectively, represents the policy rule that would be implemented for the low-ability type without any tax response to relative consumption concerns. There is no corresponding term in equation (15b) or (16b), meaning that the marginal labor and capital income tax rates implemented for the high-ability type would be zero in that case.[14] All remaining terms are proportional to μ (either measured at *t* or *t*+1) and represent, therefore, policy adjustments to relative concerns. Note that the higher μ_t, i.e., the larger the marginal social value of a decrease in $\bar{c}_t$, ceteris paribus, the higher will be the marginal labor income tax rates implemented for both ability-types. As explained in the context of equation (14) above, a high value of μ_t may either reflect that the positional externality (as measured by the average degree of positionality) is large, and/or that the low-ability type (the mimicked agent) is more positional than the mimicker. Finally, note that the marginal capital income tax rates depend on the difference between μ_t and μ_{t+1}; the greater this difference, the larger is the welfare cost of consumption in period *t* compared to period *t*+1, ceteris paribus. As a consequence, the lower will be the optimal marginal capital income tax rates.

The flexible labor income tax and residence-based capital income tax (allowing for tax-induced intercept and slope components of the individual budget constraints that may vary

[14] If all individuals share a common utility function, and if leisure is weakly separable from the other goods in the utility function, the first term on the right hand side of equation (16a) is zero. Therefore, if the social cost of relative consumption does not change over time (such that the right hand side of equation [16b] and the second term on the right hand side of equation [16a] are zero), this would reproduce the result in the seminal contribution by Ordover and Phelps (1979) for when there is no need to supplement an optimal labor income tax with marginal capital income taxation.

between ability-types and over time) together constitute a set of perfect instruments for influencing the labor supply and savings behavior, in exactly the same way as general, nonlinear labor and capital income taxes would do in a closed economy. This is also the reason as to why the policy rules for marginal income taxation derived for a closed economy carry over to the economy open to capital mobility examined here.

Note finally that the policy rules for marginal taxation in equations (15) and (16) would remain valid also if we were to relax the "small open economy assumption" and instead assume a large open economy, where the government is able to influence the world market interest rate. In a large open economy, whose government recognizes that the world market interest rate is a function of the net capital export, the results would change in two ways compared to Proposition 1. First, the optimal source-based capital income tax would no longer be equal to zero; it would, instead, follow an inverse elasticity rule based on the relationship between the world market interest rate and the net capital export. Second, the residence-based marginal capital income tax policy would have to be adjusted in response to the source-based tax such that the total marginal capital income tax rates satisfy equations (16a) and (16b).[15] In qualitative terms, the tax policy response to relative consumption concerns would be exactly the same as in the small open economy characterized in Proposition 1.

4 Optimal Tax Policy without Residence-Based Capital Income Taxes

The analysis in the preceding section presupposes that the government has access to a residence-based capital income tax. Even if the capital income taxes used in many countries share elements of both the residence and source principles, we argued in the introduction that a flexible residence-based tax requires a global information sharing system, which is likely to be difficult to implement in practice (even if steps in that direction have recently been taken). Without such a residence-based tax, Proposition 1 will no longer apply. It is thus interesting to analyze how the optimal use of the other tax instruments will change if the government is not able to freely use the residence-based tax. We will here take this argument to its extreme point by considering a scenario where the government is unable to use residence-based capital income taxation.

Without the residence-based tax, the model set out above will change in two ways. First, if $\theta_{i,t}^r \equiv 0$, then $\theta_{i,t} = \theta_t^s$ for i=1,2 and the after-tax interest rate facing domestic residents is

[15] Aronsson and Sjögren (2014) present an analogous comparison between a small and large open economy when the government attempts to correct for a self-control problem generated by quasi-hyperbolic discounting.

fixed at the world market interest rate, i.e., $r_{i,t}^n = r_t(1-\theta_t) = \bar{r}_t^n$ according to equation (4). Second, the government's budget constraint changes to read

$$0 = \sum_{i=1,2} n_{i,t}\left[\left(w_{i,t} - w_{i,t}^n\right)l_{i,t} + T_{i,t}\right] + \sum_{i=1,2} n_{i,t-1}\Phi_{i,t} + (r_t - \bar{r}_t^n)K_t \tag{17}$$

since the tax base for the source-based tax is the domestic capital stock and not the domestic savings.

The optimal tax problem is to choose the policy vector $\left(\theta_t^s, w_{i,t}^n, T_{i,t}, \Phi_{i,t+1}\right)$ for i=1,2 and all t to maximize the social welfare function in equation (11) subject to the self-selection and budget constraints in equations (12) and (17), respectively, as well as subject to equations (7), (8), and (10). In doing so, the government recognizes that $r_{i,t}^n = \bar{r}_t^n$ is exogenous. The Lagrangean is given by

$$\mathcal{L} = \sum_{t=0}^{\infty}\sum_{i=1,2} n_{i,t}U_{i,t} + \sum_{t=0}^{\infty}\lambda_t\left(U_{2,t} - \widehat{U}_{2,t}\right) + \sum_{t=0}^{\infty}\mu_t\left(\bar{c}_t - \sum_{i=1,2}\frac{\left(n_{i,t}c_{i,t} + n_{i,t-1}x_{i,t}\right)}{N_t}\right)$$
$$+\sum_{t=0}^{\infty}\gamma_t\left[\sum_{i=1,2} n_{i,t}\left[\left(w_{i,t} - w_{i,t}^n\right)l_{i,t} + T_{i,t}\right] + \sum_{i=1,2} n_{i,t-1}\Phi_{i,t} + (r_t - \bar{r}_t^n)K_t\right].$$

Let us then turn to the solution to the optimal tax problem described here. For presentational convenience, we shall make use of the second best optimal tax formulas derived in subsection 3.1 through the following short notation

$$\tau_{1,t}^* = \frac{\lambda_t^*}{w_{1,t}n_{1,t}}\left(MRS_{1,t}^{z,c} - \phi\widehat{MRS}_{2,t}^{z,c}\right) + \frac{MRS_{1,t}^{z,c}}{w_{1,t}N_t}\frac{\mu_t}{\gamma_t} \tag{18a}$$

$$\tau_{2,t}^* = \frac{MRS_{2,t}^{z,c}}{w_{2,t}N_t}\frac{\mu_t}{\gamma_t} \tag{18b}$$

$$\theta_{1,t+1}^* = \frac{\lambda_t\left(\partial\widehat{U}_{2,t}/\partial x_{1,t+1}\right)}{\gamma_{t+1}r_{t+1}n_{1,t}}\left(MRS_{1,t}^{c,x} - \widehat{MRS}_{2,t}^{c,x}\right) - \frac{1}{\gamma_{t+1}r_{t+1}}\left(\frac{\mu_t}{N_t} - MRS_{1,t}^{c,x}\frac{\mu_{t+1}}{N_{t+1}}\right) \tag{19a}$$

$$\theta_{2,t+1}^* = -\frac{1}{\gamma_{t+1}r_{t+1}}\left(\frac{\mu_t}{N_t} - MRS_{2,t}^{c,x}\frac{\mu_{t+1}}{N_{t+1}}\right). \tag{19b}$$

Equations (18) and (19) take the same form as their counterparts in equations (15) and (16); the only difference is that equations (18) and (19) are evaluated in the equilibrium examined here, which the symbol * serves to indicate. Equations (18) and (19) are thus interpretable in terms of the policy rules for marginal taxation of labor and capital income, respectively, that the government ideally would have preferred, if it had access to a full set of tax instruments.

To shorten the notation below, it is convenient to introduce the following compensated labor supply and saving responses to a change in the marginal wage rate:

$$\frac{\partial \tilde{l}_{i,t}}{\partial w_{i,t}^n} = \frac{\partial l_{i,t}}{\partial w_{i,t}^n} + l_{i,t}\frac{\partial l_{i,t}}{\partial T_{i,t}} > 0 \quad \text{and} \quad \frac{\partial \tilde{s}_{i,t}}{\partial w_{i,t}^n} = \frac{\partial s_{i,t}}{\partial w_{i,t}^n} + l_{i,t}\frac{\partial s_{i,t}}{\partial T_{i,t}}.$$

The optimal tax policy is characterized in Proposition 2.

Proposition 2. *Without the residence-based capital income tax instrument, the optimal tax policy satisfies* $\theta_i^s = 0$ *in combination with the following marginal labor income tax rates:*

$$\tau_{i,t} = \tau_{i,t}^* + \theta_{i,t+1}^* \frac{\gamma_{t+1} r_{t+1}}{\gamma_t w_{i,t}} \frac{\partial \tilde{s}_{i,t}/\partial w_{i,t}^n}{\partial \tilde{l}_{i,t}/\partial w_{i,t}^n} \text{ for } i=1,2 \text{ and all } t. \quad (20)$$

Proof: see the Appendix.

The optimal source-based capital income tax remains equal to zero also when the residence-based instrument is absent. This is so because the capital stock is still perfectly elastic from the point of view of the government, whereas the labor income tax base is not. As a consequence, only the labor income tax will be used in response to the externalities that relative consumption concerns give rise to.[16]

Note that the optimal marginal labor income tax is in this case interpretable as a weighted sum of the policy rules for marginal labor and capital income taxation that the government would ideally have preferred. We can thus think of $\tau_{i,t}^*$ and $\theta_{i,t+1}^*$ in terms of *latent* optimal tax policy rules, while the formula for $\tau_{i,t}$ is the *actual* policy rule for marginal labor income taxation when the government is constrained to the more limited set of tax instruments considered here. Therefore, $\tau_{i,t}$ is given by a weighted average of $\tau_{i,t}^*$ and $\theta_{i,t+1}^*$ with the relative weight given by the ratio of compensated savings and labor supply responses to an increase in the marginal wage rate. The intuition is that when the residence-based capital income tax instrument is absent, the marginal labor income tax will be used to correct for the effects of relative consumption concerns on two margins: the atemporal consumption-leisure margin (as before), and the intertemporal consumption margin which a residence-based capital income tax would otherwise have targeted.

[16] An immediate objection to Propositions 1 and 2 is, of course, that small open economies often use capital income taxes despite that capital is (at least close to) perfectly mobile. We would, therefore, like to emphasize that the policy incentives characterized in equation (20) remain valid as long as the residence based capital income tax is not flexible in the sense described in subsection 3.1. For instance, with a positive, yet suboptimal, residence-based capital income tax, the optimal labor income tax can still be written in a way similar to equation (20), with the modification that $\theta_{i,t+1}^*$ is replaced by $\theta_{i,t+1}^*$-$\theta_{i,t+1}$, where $\theta_{i,t+1}$ is the actual marginal capital income tax rate facing ability-type *i* of generation *t*.

Although the labor income tax is a direct instrument for influencing the atemporal consumption-leisure tradeoff, it is only an indirect (and imperfect) instrument for affecting the intertemporal consumption tradeoff. Therefore, whether the labor income tax is a useful instrument for influencing the savings behavior depends on how the saving responds to a budget neutral change in marginal labor income tax, which hints at the role of the multiplier $(\partial \tilde{s}_{i,t}/\partial w_{i,t}^n)/(\partial \tilde{l}_{i,t}/\partial w_{i,t}^n)$ attached to $\theta_{i,t+1}^*$ in equation (20). The larger (smaller) this multiplier, the larger the will be the relative weight attached to $\theta_{i,t+1}^*$ ($\tau_{i,t}^*$). Economic theory gives no clear guidance to the sign of this multiplier. Whereas the compensated labor supply is increasing in the marginal net wage rate, the corresponding compensated savings response can be either positive or negative; let be that a positive sign appears to us as the most likely outcome.[17]

Another important difference compared to subsection 3.1 is that society attaches a different marginal value to a decrease in the level of reference consumption here. In other words, the valuation procedure depends on the tax instruments that the government has at its disposal. By using the following short notations for compensated labor supply and savings responses to an increase in the level of reference consumption

$$\frac{\partial \tilde{l}_{i,t}}{\partial \bar{c}_t} = \frac{\partial l_{i,t}}{\partial \bar{c}_t} - \alpha_{i,t}^c \frac{\partial l_{i,t}}{\partial T_{i,t}}, \qquad \frac{\partial \tilde{s}_{i,t}}{\partial \bar{c}_t} = \frac{\partial s_{i,t}}{\partial \bar{c}_t} - \alpha_{i,t}^c \frac{\partial s_{i,t}}{\partial T_{i,t}},$$

$$\frac{\partial \tilde{l}_{i,t-1}}{\partial \bar{c}_t} = \frac{\partial l_{i,t-1}}{\partial \bar{c}_t} - \alpha_{i,t}^x \frac{\partial l_{i,t-1}}{\partial \Phi_{i,t}}, \qquad \frac{\partial \tilde{s}_{i,t-1}}{\partial \bar{c}_t} = \frac{\partial s_{i,t-1}}{\partial \bar{c}_t} - \alpha_{i,t}^x \frac{\partial s_{i,t-1}}{\partial \Phi_{i,t}},$$

we characterize this shadow price in Proposition 3.

Proposition 3. *Without the residence-based capital income tax instrument, the shadow price of a decrease in the level of reference consumption becomes*

$$\mu_t = \frac{\bar{\alpha}_t \gamma_t N_t}{1-\bar{\alpha}_t} - \frac{1}{1-\bar{\alpha}_t}\left[\lambda_{t-1}\frac{\partial \hat{U}_{2,t-1}}{\partial x_{1,t}}\left(\hat{\alpha}_{2,t}^x - \alpha_{1,t}^x\right) + \lambda_t \frac{\partial \hat{U}_{2,t}}{\partial c_{1,t}}\left(\hat{\alpha}_{2,t}^c - \alpha_{1,t}^c\right)\right]$$
$$-\frac{1}{1-\bar{\alpha}_t}\sum_{\mathrm{i}=1,2}\left(\gamma_t n_{i,t} w_{i,t} \Delta\tau_{i,t}\frac{\partial \tilde{l}_{i,t}}{\partial \bar{c}_t} + \gamma_{t-1} n_{i,t-1} w_{i,t-1} \Delta\tau_{i,t-1}\frac{\partial \tilde{l}_{i,t-1}}{\partial \bar{c}_t}\right)$$

[17] As long as the utility function is overall concave in consumption such that

$$\frac{\partial^2 u_{i,t}}{\partial c_{i,t}^2} + \frac{\partial^2 u_{i,t}}{\partial (\Delta_{i,t}^c)^2} + 2\frac{\partial^2 u_{i,t}}{\partial c_{i,t}\partial \Delta_{i,t}^c} < 0,$$

a sufficient (not necessary) condition for a positive sign of this derivative is that consumption and leisure are weak complements in terms of the utility function.

$$-\frac{1}{1-\bar{\alpha}_t}\sum_{i=1,2}\left(\gamma_{t+1}r_{t+1}n_{i,t}\Delta\theta_{i,t+1}\frac{\partial\tilde{s}_{i,t}}{\partial\bar{c}_t}+\gamma_t r_t n_{i,t-1}\Delta\theta_{i,t}\frac{\partial\tilde{s}_{i,t-1}}{\partial\bar{c}_t}\right) \quad (21)$$

for all t, where $\Delta\tau_{i,t}=\tau_{i,t}-\tau_{i,t}^{*}$ and $\Delta\theta_{i,t}=\theta_{i,t}-\theta_{i,t}^{*}=-\theta_{i,t}^{*}$.

Proof: see the Appendix.

The first row on the right hand side of equations (21) coincides with the shadow price derived under a full set of tax instruments given in equation (14). As such, these components are interpretable in the same general way as in the previous section. However, the second and third rows of equation (21) are novel and did not appear in equation (14). The reason as to why they vanished in equation (14) is that $\Delta\tau_{i,t}=\Delta\theta_{i,t}=0$ for all *t* in case the government has a full set of tax instrument, in which the actual policy rules coincide with the latent rules ideally preferred by the government. In a second best optimum based on a full set of tax instruments, the labor supply and savings behavior will be chosen to maximize the social welfare (which the government induces the individuals to do through tax policy), which explains why a change in the level of reference consumption did not have any welfare effects via the labor supply and savings functions in Section 3. However, when this is no longer the case, i.e., when the tax instruments are not flexible enough to allow the government to exercise perfect control over the labor supply and savings, a change in the level of reference consumption will typically affect the shadow price also via the induced responses in the individuals' labor supply and savings behavior. The terms in parenthesis in the second and third rows are reminiscent of tax revenue effects, although dependent on a discrepancy between the actual marginal tax rate and the marginal tax rate ideally preferred (i.e., the marginal tax policy that the government would chose if equipped with a full set of instruments). The reason as to why the labor supply and savings effects are compensated instead of uncompensated is that the lump-sum elements in the tax are optimally chosen, and the first order conditions for these lump-sum components are used in the calculation of equation (21).

To give a more thorough interpretation, consider the first term in parenthesis in the second row and suppose that $\Delta\tau_{i,t}$ is positive, such that the actual marginal labor income tax rate exceeds the rate implied by the government's ideal policy rule. This typically implies that individuals of ability-type *i* and generation *t* supply fewer work hours than ideally preferred, in which case an increase in the hours of work would be welfare improving. As such, if an increase in $\bar{c}_t$ leads to an increase in the hours of work (which is reasonable as one would expect people prone to conspicuous consumption to work more than they would otherwise have done) such that $\partial\tilde{l}_{i,t}/\partial\bar{c}_t > 0$, then this contributes to a decrease in the social marginal cost of the externality and thus to a lower μ_t. The interpretation of the case where $\Delta\tau_{i,t}$ is negative is analogous; yet with effects opposite to those just described. Note finally that $\bar{c}_t$ also affects generation *t*-1, meaning that the second term in parenthesis in the second row can be interpreted in a similar way.

The third row in equation (21) appears because a change in the level of reference consumption affects the savings behavior, and the terms in brackets are interpretable in the same general way as their counterparts in the second row. To exemplify, consider the first term in parenthesis which is proportional to $\Delta\theta_{i,t+1}$. If $\Delta\theta_{i,t+1} > 0$, the actual marginal capital tax rate – which is zero here - exceeds the rate implied by the policy rule ideally preferred by the government in equation (19a) or (19b). This typically implies that individuals of ability-type *i* and generation *t* save less than the government would have liked them to do, ceteris paribus, meaning that increased savings would lead to higher welfare. Therefore, if an increase in the level of reference contributes to less savings in the sense that $\tilde{s}_{i,t}/\partial\bar{c}_t < 0$ – which seems plausible to us - then this effect contributes to increase the social marginal cost of the externality which, in turn, implies a higher μ_t. By analogy, if $\Delta\theta_{i,t+1} < 0$ while the other conditions remain as above, the first term in the second row would instead reduce the social marginal cost of the externality and, therefore, contribute to a lower μ_t.

Interpretation Based on a Simplified Model

To go further and examine whether the restriction imposed on the capital income tax induces the government to implement higher or lower marginal labor income tax rates than it would have done with a full set of tax instruments, we will discuss a simplified version of the model by adding two quite restrictive assumptions: (i) the self-selection constraint does not bind (such that $\lambda_t = 0$ for all *t*), and (ii) the individuals' lifetime utility functions are additive and linear in the two measures of relative consumption. The second assumption means that equation (2) simplifies to read

$$U_{i,t} = \hat{u}_{i,t}(c_{i,t}, z_{i,t}, x_{i,t+1}) + k^c\Delta^c_{i,t} + k^x\Delta^x_{i,t+1} \tag{22}$$

for i=1,2 and all t, where $k^c > 0$ and $k^x > 0$ are fixed parameters. This functional form implies that the labor supply and saving functions become $l_{i,t} = l_{i,t}(w^n_{i,t}, \bar{r}^n_t, T_{i,t}\Phi_{i,t+1})$ and

$s_{i,t} = s_{i,t}(w_{i,t}^n, \bar{r}_t^n, T_{i,t}\Phi_{i,t+1})$, respectively, which do not directly depend on the reference consumption levels. Furthermore, under assumptions (i) and (ii) equation (21) reduces to read $\mu_t = \bar{\alpha}_t \gamma_t N_t/(1-\bar{\alpha}_t) > 0$, which reflects that a ceteris paribus decrease in the level of reference consumption constitutes a pure efficiency gain through a smaller positional externality. Based on these additional assumptions, equation (20) reduces to (for *i*=1,2)

$$\tau_{i,t} = \frac{MRS_{i,t}^{z,c}}{w_{i,t}} \frac{\bar{\alpha}_t}{(1-\bar{\alpha}_t)} - \left(\frac{\bar{\alpha}_t}{(1-\bar{\alpha}_t)} - MRS_{i,t}^{c,x} \frac{\gamma_{t+1}}{\gamma_t} \frac{\bar{\alpha}_{t+1}}{(1-\bar{\alpha}_{t+1})}\right) \frac{1}{w_{i,t}} \frac{\partial \tilde{s}_{i,t}/\partial w_{i,t}^n}{\partial \tilde{l}_{i,t}/\partial w_{i,t}^n}. \quad (23)$$

Note also that if the government can borrow/lend in the international capital market at the interest rate $\bar{r}_t^n$, then $\gamma_t = (1+\bar{r}_t^n)\gamma_{t+1}$ which, in turn, implies that $MRS_{i,t}^{c,x}\gamma_{t+1}/\gamma_t = 1$. We can then derive the following corollary to Proposition 2:

Corollary 1. *Consider the special case where the self-selection constraint does not bind, the utility function takes the form of equation (22), and the government can borrow/lend abroad. Equation (20) then implies the following:*

(1) If $\partial \tilde{s}_{i,t}/\partial w_{i,t}^n > 0$, *then*

$$\tau_{i,t} > \tau_{i,t}^* \textit{ iff } \bar{\alpha}_{t+1} > \bar{\alpha}_t, \textit{ and } \tau_{i,t} < \tau_{i,t}^* \textit{ iff } \bar{\alpha}_{t+1} < \bar{\alpha}_t.$$

(2) If $\partial \tilde{s}_{i,t}/\partial w_{i,t}^n < 0$, *then*

$$\tau_{i,t} < \tau_{i,t}^* \textit{ iff } \bar{\alpha}_{t+1} > \bar{\alpha}_t, \textit{ and } \tau_{i,t} > \tau_{i,t}^* \textit{ iff } \bar{\alpha}_{t+1} < \bar{\alpha}_t.$$

(3) If $\bar{\alpha}_{t+1} = \bar{\alpha}_t$, *then* $\tau_{i,t} = \tau_{i,t}^*$.

We will base most of the interpretation below on the case where the multiplier $\partial \tilde{s}_{i,t}/\partial w_{i,t}^n$ is positive (which appears to us as the most realistic one). Let us first observe that if the self-selection constraint does not bind and the utility functions are given as in equation (22), we have (as long as $\gamma_t = (1+\bar{r}_t^n)\gamma_{t+1}$)

$$sign\ \theta_{1,t+1}^* = sign\ (\bar{\alpha}_{t+1} - \bar{\alpha}_t).$$

Therefore, $\bar{\alpha}_{t+1} > \bar{\alpha}_t$ means that the government would ideally have preferred to implement a positive marginal capital tax in order to reduce savings, since the marginal positional externality increases over time, i.e., the positional externality is larger in period t+1 than in period *t*. However, since this option is not available by assumption, the government uses the labor tax as an indirect (and imperfect) instrument to deter savings. If the compensated savings measure increases in response to an increase in the marginal wage rate such that $\partial\tilde{s}_{i,t}/\partial w_{i,t}^{n} > 0$, which is the case addressed in part (1) of the corollary, this is accomplished through a higher marginal labor income tax rate. The case where $\bar{\alpha}_{t+1} < \bar{\alpha}_{t}$ correspondingly implies an incentive for the government to induce individuals to save more, which is accomplished through a lower marginal labor income tax rate.

The interpretation of part (2) of the corollary is analogous, except that this case is based on the assumption that $\partial\tilde{s}_{i,t}/\partial w_{i,t}^{n} < 0$. The qualitative implications for policy will then be the opposite to those just described. Turning finally to part (3), $\bar{\alpha}_{t+1} = \bar{\alpha}_{t}$ means $\theta_{1,t+1}^{*} = 0$. In other words, since the marginal positional externality does not change between periods *t* and *t*+1, the desire to correct for positional externalities provides no incentive for the government to modify the intertemporal consumption tradeoff faced by consumers. As a consequence, the absence of the residence-based capital income tax instrument does not lead to any modification of the policy rule for marginal labor income taxation.

The assumptions behind Corollary 1 are useful by allowing us to relate the relationship between $\tau_{i,t}$ and $\tau_{i,t}^{*}$ to the core mechanisms behind the relative consumption concerns. An important question is whether these insights carry over to a second best scenario with a binding self-selection constraint. It turns out that they do, albeit with some modification. If we continue to assume that the life-time utility functions are linear in the measures of relative consumption (allowing us to avoid the indirect effects of $\bar{c}_{t}$ on μ_{t} that are due to labor supply and savings responses), while at the same time assuming that the self-selection constraint binds, it turns out that the social shadow price of a decrease in the level of reference consumption takes the form of equation (14). In other words, it takes the same forms as it would have taken if the government had a full set of tax instruments. If we follow Aronsson and Johansson-Stenman (2010) and define the following summary measure of differences in the degree of positionality between the mimicker and the low-ability type in period *t*:

$$\alpha_{t}^{d} = \frac{1}{\gamma_{t} N_{t}}\left[\lambda_{t-1}\frac{\partial\hat{U}_{2,t-1}}{\partial x_{1,t}}\left(\hat{\alpha}_{2,t}^{x} - \alpha_{1,t}^{x}\right) + \lambda_{t}\frac{\partial\hat{U}_{2,t}}{\partial c_{1,t}}\left(\hat{\alpha}_{2,t}^{c} - \alpha_{1,t}^{c}\right)\right] \tag{24}$$

this shadow price can then be written as

$$\mu_t = N_t\, \gamma_t \frac{\bar{\alpha}_t - \alpha_t^d}{1-\bar{\alpha}_t}. \tag{25}$$

Therefore, Corollary 2 continues to remain valid for the high-ability type with the only modification that the relevant difference in positionality over time now in measured by

$$(\bar{\alpha}_{t+1} - \alpha_{t+1}^d)/(1-\bar{\alpha}_{t+1}) - (\bar{\alpha}_t - \alpha_t^d)/(1-\bar{\alpha}_t) \tag{26}$$

instead of by $\bar{\alpha}_{t+1} - \bar{\alpha}_t$. The reason is, of course, that the social marginal benefit of decreased reference consumption at any time *t* will now also depend on whether mimickers are predominantly more ($\alpha_t^d > 0$) or less ($\alpha_t^d < 0$) positional than low-ability individuals. Part 1 of the corollary, which is based on the assumption that $\partial \tilde{s}_{i,t}/\partial w_{i,t}^n > 0$, will then be modified as follows for the high-ability type: $\tau_{2,t} > (<)\ \tau_{2,t}^*$ iff (26) is positive (negative), and the modifications of parts 2 and 3 are analogous. For the low-ability type, it is not equally straight forward to adjust Corollary 1 to a second best economy with a binding self-selection constraint, since $\theta_{1,t+1}^*$ now also depends on whether the marginal rate of substitution between present and future consumption facing the low-ability type exceeds, or falls short of, the corresponding marginal rate of substitution facing the mimicker. Therefore, to generalize the corollary for the low-ability type, we would also have to add $MRS_{1,t}^{c,x} > (<) \widehat{MRS}_{2,t}^{c,x}$ to the other conditions required for $\tau_{1,t} > (<)\ \tau_{1,t}^*$.

This leads naturally to a second corollary to Proposition 2, focusing on the special case where the consumers are not concerned with relative consumption at all,[18] in which case $\mu_t = 0$. This case thus shows how the tax policy in the conventional closed-economy two-type model would be modified in an open economy where the residence-based capital income tax instrument is absent.

Corollary 2. *Suppose that the consumers are not concerned with their relative consumption compared to others. Equation (20) then implies the following:*

(1) If $\partial \tilde{s}_{1,t}/\partial w_{1,t}^n > 0$, *then*

$$\tau_{1,t} > \tau_{1,t}^* \ \text{ iff } MRS_{1,t}^{c,x} > \widehat{MRS}_{2,t}^{c,x}, \text{ and } \ \tau_{1,t} < \tau_{1,t}^* \ \text{ iff } MRS_{1,t}^{c,x} < \widehat{MRS}_{2,t}^{c,x}.$$

(2) If $\partial \tilde{s}_{1,t}/\partial w_{1,t}^n < 0$, *then*

[18] That is $\frac{\partial u_{i,t}}{\partial \Delta_{i,t}^c} = \frac{\partial u_{i,t}}{\partial \Delta_{i,t+1}^x} = 0$.

$$\tau_{1,t} < \tau^*_{1,t} \ \ iff \, MRS^{c,x}_{1,t} > \widehat{MRS}^{c,x}_{2,t}, \ and \ \ \tau_{1,t} > \tau^*_{1,t} \ \ iff \, MRS^{c,x}_{1,t} < \widehat{MRS}^{c,x}_{2,t}.$$

(3) If $MRS^{c,x}_{1,t} = \widehat{MRS}^{c,x}_{2,t}$, *then* $\tau_{1,t} = \tau^*_{1,t}$.

(4) $\tau_{2,t} = \tau^*_{2,t} = 0$.

In the absence of any relative consumption comparisons, and if the government had access to a full set of instruments, only the low-ability type's income would be subject to marginal taxation. In that case, the incentive to marginally tax or subsidize the low-ability type's capital income would depend on whether the low-ability type attaches a larger or smaller marginal value to early-in-life (compared to later-in-life) consumption than the mimicker, i.e., whether $MRS^{c,x}_{1,t}$ exceeds, or falls short of, $\widehat{MRS}^{c,x}_{2,t}$. This corresponds to the marginal capital income tax policy for a closed economy, which is analyzed in Brett (1997). Therefore, in an economy open to capital mobility, and where the government lacks a residence-based capital tax instrument, the marginal labor income tax implemented for the low-ability type will be modified correspondingly. The marginal labor income tax rate implemented for the high-ability type remains equal to zero (as in a conventional two-type model).

5. Conclusions

As far as we know, this is the first paper analyzing optimal capital and labor income taxation in an economy which is open to capital mobility, and where people are concerned with their relative consumption. The framework is that of a small open economy where capital is perfectly mobile while people (in the form of overlapping generations) are not, and where the government uses nonlinear taxation for purposes of redistribution and correction for positional externalities.

The take home message of the paper is that the tax policy response to relative consumption concerns crucially depends on whether the government can perfectly observe (and hence tax) returns on savings abroad, such that residence-based capital income taxes can be used to their full potential. With a full set of tax instruments, including a flexible residence-based capital income tax, marginal income tax policies derived for a closed economy largely carry over to the small open economy analyzed here. In contrast, when returns on savings abroad cannot be observed, the optimal tax policy rules become very different. In this case, also capital income taxes on domestic savings will be completely ineffective, since such taxes would induce the consumers to move their savings abroad. As a consequence, there is no room for capital income taxation anymore, and the labor income tax must therefore indirectly also reflect the corrective purpose that the absent capital income tax would otherwise have had. The policy rules for marginal labor income taxation then become rather complex in the sense of reflecting both the conventional second-best problem due to asymmetric information, since the ability-type cannot be observed directly, and another second-best problem due to that capital income taxation cannot be used. Among other results, we show that the optimal marginal labor income tax rate implemented for any ability-type can be written as a weighted sum of two components: (*i*) the policy rule for marginal labor income taxation the government would have implemented if the residence-based capital income tax instrument were available (without restrictions), and (*ii*) the policy rule for marginal capital income taxation the government would have chosen if the residence-based instrument were available. The compensated savings response to an increase in the marginal labor income tax rate largely determines the effectiveness of the labor income tax as an (indirect) instrument to correct for intertemporal positional externalities.

While this paper has taken large steps towards understanding optimal income taxation when the residents of a small open economy engage in status comparisons, there are several possible extensions for future research. First, we have assumed away labor mobility completely in order to keep the analysis as simple as possible. Although we conjecture that most qualitative results will continue to hold in a more general framework with imperfect labor mobility, such an extension would still be useful, not least as a basis on which to develop a numerical model of optimal taxation for an open economy. Second, we have solely focused on a single country and thus neither addressed the welfare costs of strategic interaction nor the scope for tax policy cooperation between different countries. As a consequence, there is still room for much more work on redistributive taxation and public expenditure in economies where people care about social comparisons.

Appendix

Proof of Proposition 1

Proposition 1 addresses the optimal tax policy implemented for generation t when the government has access to a full set of tax instruments.

Source-based capital tax

The first order condition for θ_t^s can be written as

$$\sum_{i=1,2}\left[\frac{\partial w_{i,t}}{\partial \theta_t^s} n_{i,t} l_{i,t} + \frac{\partial r_t}{\partial \theta_t^s} s_{i,t-1}\right] - r_t Q_t - \theta_t^s \frac{\partial r_t}{\partial \theta_t^s} Q_t - \theta_t^s r_t \frac{\partial Q_t}{\partial \theta_t^s} = 0. \tag{A1}$$

By using $K_t = \sum_i s_{i,t-1} - Q_t$, and $\sum_i (\partial w_{i,t}/\partial \theta_t^s)\, n_{i,t} l_{i,t} + (\partial r_t/\partial \theta_t^s) K_t = 0$ from the zero profit condition, equation (A1) can be rewritten to read

$$-r_t Q_t + (1-\theta_t^s)\frac{\partial r_t}{\partial \theta_t^s} Q_t - \theta_t^s r_t \frac{\partial Q_t}{\partial \theta_t^s} = 0. \tag{A2}$$

Finally, since $\bar{r}_t^n$ is treated as exogenous by the government of the small open economy, equation (4) implies $(\partial r_t/\partial \theta_t^s)(1-\theta_t^s) = r_t$. Substituting into equation (A2) gives $\theta_t^s = 0$.

Marginal Labor and Capital Income Tax Rates

The first order conditions for $w_{1,t}^n$, $T_{1,t}$, $r_{1,t+1}^n$, and $\Phi_{1,t+1}$, respectively, which are used to derive the optimal marginal income tax rates implemented for the low-ability type, can be written as follows, if we use $\theta_t^s = 0$ and the equilibrium condition given by equation (4):

$$\begin{aligned} 0 = \frac{\partial \mathcal{L}}{\partial w_{1,t}} &= n_{1,t} l_{1,t}\left[\left(\frac{\partial U_{1,t}}{\partial c_{1,t}} + \frac{\partial U_{1,t}}{\partial \Delta_{1,t}^c}\right) - \gamma_t\right] + \gamma_t n_{1,t}\big(w_{1,t} - w_{1,t}^n\big)\frac{\partial l_{1,t}}{\partial w_{i,t}^n} \\ &+\gamma_{t+1} n_{1,t}\big(r_{t+1} - r_{1,t+1}^n\big)\frac{\partial s_{1,t}}{\partial w_{1,t}^n} - \mu_t \frac{n_{1,t}}{N_t}\frac{\partial c_{1,t}}{\partial w_{1,t}^n} - \mu_{t+1}\frac{n_{1,t}}{N_{t+1}}\frac{\partial x_{1,t+1}}{\partial w_{1,t}^n} \\ &-\lambda_t\left[l_{1,t}\left(\frac{\partial \hat{U}_{2,t}}{\partial c_{1,t}} + \frac{\partial \hat{U}_{2,t}}{\partial \Delta_{i,t}^c}\right) + \left\{w_{1,t}^n\left(\frac{\partial \hat{U}_{2,t}}{\partial c_{1,t}} + \frac{\partial \hat{U}_{2,t}}{\partial \Delta_{1,t}^c}\right) - \phi\frac{\partial \hat{U}_{2,t}}{\partial \hat{z}_{1,t}}\right\}\frac{\partial l_{1,t}}{\partial w_{1,t}^n}\right] \\ &-\lambda_t\left[\big(1 + r_{1,t+1}^n\big)\left(\frac{\partial \hat{U}_{2,t}}{\partial x_{1,t+1}} + \frac{\partial \hat{U}_{2,t}}{\partial \Delta_{1,t+1}^x}\right) - \left(\frac{\partial \hat{U}_{2,t}}{\partial c_{1,t}} + \frac{\partial \hat{U}_{2,t}}{\partial \Delta_{1t}^c}\right)\right]\frac{\partial s_{1,t}}{\partial w_{1,t}^n} \end{aligned} \tag{A3a}$$

$$\begin{aligned} 0 = \frac{\partial \mathcal{L}}{\partial T_{1,t}} &= -n_{1,t}\left[\left(\frac{\partial U_{1,t}}{\partial c_{1,t}} + \frac{\partial U_{1,t}}{\partial \Delta_{1,t}^c}\right) - \gamma_t\right] + \gamma_t n_{1,t}\big(w_{1,t} - w_{1,t}^n\big)\frac{\partial l_{1,t}}{\partial T_{1,t}} \\ &+\gamma_{t+1} n_{1,t}\big(r_{t+1} - r_{1,t+1}^n\big)\frac{\partial s_{1,t}}{\partial T_{1,t}} - \mu_t \frac{n_{1,t}}{N_t}\frac{\partial c_{1,t}}{\partial T_{1,t}} - \mu_{t+1}\frac{n_{1,t}}{N_{t+1}}\frac{\partial x_{1,t+1}}{\partial T_{1,t}} \\ &-\lambda_t\left[-\left(\frac{\partial \hat{U}_{2,t}}{\partial c_{1,t}} + \frac{\partial \hat{U}_{2,t}}{\partial \Delta_{1,t}^c}\right) + \left\{w_{1t}^n\left(\frac{\partial \hat{U}_{2,t}}{\partial c_{1,t}} + \frac{\partial \hat{U}_{2,t}}{\partial \Delta_{1,t}^c}\right) - \phi\frac{\partial \hat{U}_{2,t}}{\partial \hat{z}_{1,t}}\right\}\frac{\partial l_{1,t}}{\partial T_{1,t}}\right] \\ &-\lambda_t\left[\big(1 + r_{1,t+1}^n\big)\left(\frac{\partial \hat{U}_{2,t}}{\partial x_{1,t+1}} + \frac{\partial \hat{U}_{2,t}}{\partial \Delta_{1,t+1}^x}\right) - \left(\frac{\partial \hat{U}_{2,t}}{\partial c_{1,t}} + \frac{\partial \hat{U}_{2,t}}{\partial \Delta_{1,t}^c}\right)\right]\frac{\partial s_{1,t}}{\partial T_{1,t}} \end{aligned} \tag{A3b}$$

$$0 = \frac{\partial \mathcal{L}}{\partial r_{1,t+1}^n} = n_{1,t} s_{1,t}\left[\left(\frac{\partial U_{1,t}}{\partial x_{1,t+1}} + \frac{\partial U_{1,t}}{\partial \Delta_{1,t+1}^x}\right) - \gamma_{t+1}\right] + \gamma_t n_{1,t}\big(w_{1,t} - w_{1,t}^n\big)\frac{\partial l_{1,t}}{\partial r_{1,t+1}^n}$$

$$+\gamma_{t+1} n_{1,t}\left(r_{t+1} - r_{1,t+1}^{n}\right)\frac{\partial s_{1,t}}{\partial r_{1,t+1}^{n}} - \mu_t \frac{n_{1,t}}{N_t}\frac{\partial c_{1,t}}{\partial r_{1,t+1}^{n}} - \mu_{t+1}\frac{n_{1,t}}{N_{t+1}}\frac{\partial x_{1,t+1}}{\partial r_{1,t+1}^{n}}$$

$$-\lambda_t\left[\left\{w_{1,t}^{n}\left(\frac{\partial \widehat{U}_{2,t}}{\partial c_{1,t}} + \frac{\partial \widehat{U}_{2,t}}{\partial \Delta_{i,t}^{c}}\right) - \phi\frac{\partial \widehat{U}_{2,t}}{\partial \hat{z}_{1,t}}\right\}\frac{\partial l_{1,t}}{\partial r_{i,t+1}^{n}} + s_{1,t}\left(\frac{\partial \widehat{U}_{2,t}}{\partial x_{1,t+1}} + \frac{\partial \widehat{U}_{2,t}}{\partial \Delta_{1,t+1}^{x}}\right)\right]$$

$$-\lambda_t\left[\left(1 + r_{1,t+1}^{n}\right)\left(\frac{\partial \widehat{U}_{2,t}}{\partial x_{1,t+1}} + \frac{\partial \widehat{U}_{2,t}}{\partial \Delta_{1,t+1}^{x}}\right) - \left(\frac{\partial \widehat{U}_{2,t}}{\partial c_{1,t}} + \frac{\partial \widehat{U}_{2,t}}{\partial \Delta_{i,t}^{c}}\right)\right]\frac{\partial s_{1,t}}{\partial r_{1,t+1}^{n}} \qquad \text{(A3c)}$$

$$0 = \frac{\partial \mathcal{L}}{\partial \Phi_{1,t+1}} = -n_{1,t}\left[\left(\frac{\partial U_{1,t}}{\partial x_{1,t+1}} + \frac{\partial U_{1,t}}{\partial \Delta_{1,t+1}^{x}}\right) - \gamma_{t+1}\right] + \gamma_t n_{1,t}\left(w_{1,t} - w_{1,t}^{n}\right)\frac{\partial l_{1,t}}{\partial \Phi_{1,t+1}}$$

$$+\gamma_{t+1} n_{1,t}\left(r_{t+1} - r_{1,t+1}^{n}\right)\frac{\partial s_{1,t}}{\partial \Phi_{1,t+1}} - \mu_t \frac{n_{1,t}}{N_t}\frac{\partial c_{1,t}}{\partial \Phi_{1,t+1}} - \mu_{t+1}\frac{n_{1,t}}{N_{t+1}}\frac{\partial x_{1,t+1}}{\partial \Phi_{1,t+1}}$$

$$-\lambda_t\left[\left\{w_{1,t}^{n}\left(\frac{\partial \widehat{U}_{2,t}}{\partial c_{1,t}} + \frac{\partial \widehat{U}_{2,t}}{\partial \Delta_{1,t}^{c}}\right) - \phi\frac{\partial \widehat{U}_{2,t}}{\partial \hat{z}_{1,t}}\right\}\frac{\partial l_{1,t}}{\partial \Phi_{1,t+1}} - \left(\frac{\partial \widehat{U}_{2,t}}{\partial x_{1,t+1}} + \frac{\partial \widehat{U}_{2,t}}{\partial \Delta_{1,t+1}^{x}}\right)\right]$$

$$-\lambda_t\left[\left(1 + r_{1,t+1}^{n}\right)\left(\frac{\partial \widehat{U}_{2,t}}{\partial x_{1,t+1}} + \frac{\partial \widehat{U}_{2,t}}{\partial \Delta_{1,t+1}^{x}}\right) - \left(\frac{\partial \widehat{U}_{2,t}}{\partial c_{1,t}} + \frac{\partial \widehat{U}_{2,t}}{\partial \Delta_{1,t}^{c}}\right)\right]\frac{\partial s_{1,t}}{\partial \Phi_{1,t+1}}. \qquad \text{(A3d)}$$

In equations (A3a)-(A3d), we have used the short notations

$$\frac{\partial c_{1,t}}{\partial w_{1,t}^{n}} = l_{1,t} + w_{1,t}^{n}\frac{\partial l_{1,t}}{\partial w_{1,t}^{n}} - \frac{\partial s_{1,t}}{\partial w_{1,t}^{n}}$$

$$\frac{\partial c_{1,t}}{\partial T_{1,t}} = -1 + w_{1,t}^{n}\frac{\partial l_{1,t}}{\partial T_{1,t}} - \frac{\partial s_{1,t}}{\partial T_{1,t}}$$

$$\frac{\partial c_{1,t}}{\partial r_{1,t+1}^{n}} = w_{1,t}^{n}\frac{\partial l_{1,t}}{\partial r_{1,t+1}^{n}} - \frac{\partial s_{1,t}}{\partial r_{1,t+1}^{n}}$$

$$\frac{\partial c_{1,t}}{\partial \Phi_{1,t+1}} = w_{1,t}^{n}\frac{\partial l_{1,t}}{\partial \Phi_{1,t+1}} - \frac{\partial s_{1,t}}{\partial \Phi_{1,t+1}}$$

$$\frac{\partial x_{1,t+1}}{\partial w_{1,t}^{n}} = \left(1 + r_{1,t+1}^{n}\right)\frac{\partial s_{1,t}}{\partial w_{1,t}^{n}}$$

$$\frac{\partial x_{1,t+1}}{\partial T_{1,t}} = \left(1 + r_{1,t+1}^{n}\right)\frac{\partial s_{1,t}}{\partial T_{1,t}}$$

$$\frac{\partial x_{1,t+1}}{\partial r_{1,t+1}^{n}} = s_{1,t} + \left(1 + r_{1,t+1}^{n}\right)\frac{\partial s_{1,t}}{\partial r_{1,t+1}^{n}}$$

$$\frac{\partial x_{1,t+1}}{\partial \Phi_{1,t+1}} = -1 + \left(1 + r_{1,t+1}^{n}\right)\frac{\partial s_{1,t}}{\partial \Phi_{1,t+1}}.$$

The corresponding first order conditions for $w_{2,t}^n$, $T_{2,t}$, $r_{2,t+1}^n$, and $\Phi_{2,t+1}$, respectively, which are used to derive the marginal income tax rates implemented for the high-ability type, are written as follows:

$$0=\frac{\partial\mathcal{L}}{\partial w_{2,t}}=\left[(n_{2,t}+\lambda_t)l_{2,t}\left(\frac{\partial U_{2,t}}{\partial c_{2,t}}+\frac{\partial U_{2,t}}{\partial\Delta_{2,t}^c}\right)-n_{2,t}\gamma_t\right]+\gamma_t n_{2,t}\left(w_{2,t}-w_{2,t}^n\right)\frac{\partial l_{2,t}}{\partial w_{2,t}^n}$$
$$+\gamma_{t+1}n_{2,t}\left(r_{t+1}-r_{2,t+1}^n\right)\frac{\partial s_{2,t}}{\partial w_{2,t}^n}-\mu_t\frac{n_{2,t}}{N_t}\frac{\partial c_{2,t}}{\partial w_{2,t}^n}-\mu_{t+1}\frac{n_{2,t}}{N_{t+1}}\frac{\partial x_{2,t+1}}{\partial w_{2,t}^n}\qquad\text{(A3e)}$$

$$0=\frac{\partial\mathcal{L}}{\partial T_{2,t}}=-\left[(n_{2,t}+\lambda_t)\left(\frac{\partial U_{2,t}}{\partial c_{2,t}}+\frac{\partial U_{2,t}}{\partial\Delta_{2,t}^c}\right)-\gamma_t\right]+\gamma_t n_{2,t}\left(w_{2,t}-w_{2,t}^n\right)\frac{\partial l_{2,t}}{\partial T_{2,t}}$$
$$+\gamma_{t+1}n_{2,t}\left(r_{t+1}-r_{2,t+1}^n\right)\frac{\partial s_{2,t}}{\partial T_{2,t}}-\mu_t\frac{n_{2,t}}{N_t}\frac{\partial c_{2,t}}{\partial T_{2,t}}-\mu_{t+1}\frac{n_{2,t}}{N_{t+1}}\frac{\partial x_{2,t+1}}{\partial T_{2,t}}\qquad\text{(A3f)}$$

$$0=\frac{\partial\mathcal{L}}{\partial r_{2,t+1}^n}=s_{2,t}\left[(n_{2,t}+\lambda_t)\left(\frac{\partial U_{2,t}}{\partial x_{2,t+1}}+\frac{\partial U_{2,t}}{\partial\Delta_{2,t+1}^x}\right)-n_{2,t}\gamma_{t+1}\right]+\gamma_t n_{2,t}\left(w_{2,t}-w_{2,t}^n\right)\frac{\partial l_{2,t}}{\partial r_{2,t+1}^n}$$
$$+\gamma_{t+1}n_{2,t}\left(r_{t+1}-r_{2,t+1}^n\right)\frac{\partial s_{2,t}}{\partial r_{2,t+1}^n}-\mu_t\frac{n_{2,t}}{N_t}\frac{\partial c_{2,t}}{\partial r_{2,t+1}^n}-\mu_{t+1}\frac{n_{2,t}}{N_{t+1}}\frac{\partial x_{2,t+1}}{\partial r_{2,t+1}^n}\qquad\text{(A3g)}$$

$$0=\frac{\partial\mathcal{L}}{\partial\Phi_{2,t+1}}=-\left[(n_{2,t}+\lambda_{t)}\left(\frac{\partial U_{2,t}}{\partial x_{2,t+1}}+\frac{\partial U_{2,t}}{\partial\Delta_{2,t+1}^x}\right)-n_{2,t}\gamma_{t+1}\right]+\gamma_t n_{2,t}\left(w_{2,t}-w_{2,t}^n\right)\frac{\partial l_{2,t}}{\partial\Phi_{2,t+1}}$$
$$+\gamma_{t+1}n_{2,t}\left(r_{t+1}-r_{2,t+1}^n\right)\frac{\partial s_{2,t}}{\partial\Phi_{2,t+1}}-\mu_t\frac{n_{2,t}}{N_t}\frac{\partial c_{2,t}}{\partial\Phi_{2,t+1}}-\mu_{t+1}\frac{n_{2,t}}{N_{t+1}}\frac{\partial x_{2,t+1}}{\partial\Phi_{2,t+1}}\qquad\text{(A3h)}$$

where

$$\frac{\partial c_{2,t}}{\partial w_{2,t}^n}=l_{2,t}+w_{2,t}^n\frac{\partial l_{2,t}}{\partial w_{2,t}^n}-\frac{\partial s_{2,t}}{\partial w_{2,t}^n}$$
$$\frac{\partial c_{2,t}}{\partial T_{2,t}}=-1+w_{2,t}^n\frac{\partial l_{2,t}}{\partial T_{2,t}}-\frac{\partial s_{2,t}}{\partial T_{2,t}}$$
$$\frac{\partial c_{2,t}}{\partial r_{2,t+1}^n}=w_{2,t}^n\frac{\partial l_{2,t}}{\partial r_{2,t+1}^n}-\frac{\partial s_{2,t}}{\partial r_{2,t+1}^n}$$
$$\frac{\partial c_{2,t}}{\partial\Phi_{2,t+1}}=w_{2,t}^n\frac{\partial l_{2,t}}{\partial\Phi_{2,t+1}}-\frac{\partial s_{2,t}}{\partial\Phi_{2,t+1}}$$
$$\frac{\partial x_{2,t+1}}{\partial w_{2,t}^n}=\left(1+r_{2,t+1}^n\right)\frac{\partial s_{2,t}}{\partial w_{2,t}^n}$$
$$\frac{\partial x_{2,t+1}}{\partial T_{2,t}}=\left(1+r_{2,t+1}^n\right)\frac{\partial s_{2,t}}{\partial T_{2,t}}$$

$$\frac{\partial x_{2,t+1}}{\partial r_{2,t+1}^n} = s_{2,t} + \left(1 + r_{2,t+1}^n\right) \frac{\partial s_{2,t}}{\partial r_{2,t+1}^n}$$

$$\frac{\partial x_{2,t+1}}{\partial \Phi_{2,t+1}} = -1 + \left(1 + r_{2,t+1}^n\right) \frac{\partial s_{2,t}}{\partial \Phi_{2,t+1}}.$$

Consider first the marginal labor income and capital income tax rates implemented for the low-ability type. Multiply the right hand side of equation (A3b) by $l_{1,t}$ and add the resulting expression to the right hand side of equation (A3a). This gives, after some manipulations,

$$\gamma_t n_{1,t} \Omega_{1,t} \left(\frac{\partial l_{1,t}}{\partial w_{1,t}^n} + \frac{\partial l_{1,t}}{\partial T_{1,t}} l_{1,t} \right) + \gamma_{t+1} n_{1,t} \Psi_{1,t} \left(\frac{\partial s_{1,t}}{\partial w_{1,t}^n} + \frac{\partial s_{1,t}}{\partial T_{1,t}} l_{1,t} \right) = 0 \tag{A4}$$

where

$$\Omega_{1,t} = \tau_{1,t} w_{1,t} - \frac{\lambda_t^*}{n_{1,t}} \left(MRS_{1,t}^{z,c} - \phi \widehat{MRS}_{2,t}^{z,c} \right) + \frac{MRS_{1,t}^{z,c}}{N_t} \frac{\mu_t}{\gamma_t} \tag{A5}$$

$$\Psi_{1,t} = \theta_{1,t+1} r_{t+1} - \frac{\lambda_t (\partial \hat{U}_{2,t} / \partial x_{1,t+1})}{\gamma_{t+1} n_{1,t}} \left(MRS_{1,t}^{c,x} - \widehat{MRS}_{2,t}^{c,x} \right) + \frac{1}{\gamma_{t+1}} \left(\frac{\mu_t}{N_t} - MRS_{1,t}^{c,x} \frac{\mu_{t+1}}{N_{t+1}} \right). \tag{A6}$$

Similarly, multiply the right hand side of equation (A3d) by $s_{1,t}$ and add the resulting expression to the right hand side of equation (A3c). This gives

$$\gamma_t n_{1,t} \Omega_{1,t} \left(\frac{\partial l_{1,t}}{\partial r_{1,t+1}^n} + \frac{\partial l_{1,t}}{\partial \Phi_{1,t+1}} s_{1,t} \right) + \gamma_{t+1} n_{1,t} \Psi_{1,t} \left(\frac{\partial s_{1,t}}{\partial r_{1,t+1}^n} + \frac{\partial s_{1,t}}{\partial \Phi_{1,t+1}} s_{1,t} \right) = 0. \tag{A7}$$

Equation system (A4) and (A7) is solved by setting $\Omega_{1,t} = 0$ and $\Psi_{1,t} = 0$, which gives the marginal labor income and capital income tax rates for the low-ability type in equation (15a) and (15b), respectively. The marginal labor income and capital income tax rates implemented for the high-ability type can be derived in exactly the same way by using equations (A3e)-(A3h).■

Proof of Proposition 2

Proposition 2 derives the marginal labor income tax rates and the source-based capital income tax in the case where the residence-based capital income tax instrument is absent, in which $r_{i,t+1}^n$ no longer constitutes a decision-variable for the government. By using the same type of calculations as in equations (A1) and (A2), it follows that $\theta_t^s = 0$ also in this case.

Turning to marginal labor income taxation, consider once again the formula implemented for the low-ability type. The first order conditions for $w_{1,t}^n$, $T_{1,t}$, and $\Phi_{1,t+1}$ take the same general form as in equations (A3a), (A3b), (A3d), respectively, with the modification that $r_{i,t+1}^{n} = \bar{r}_{t}^{n}$ for i=1,2. Since $\theta_t^s = 0$, this also means that $r_t - r_{1,t+1}^n = 0$ in equations (A3a), (A3b), and (A3d). The analogue to equation (A4) can thus be written as

$$\gamma_t n_{1,t}\Omega_{1,t}\left(\frac{\partial l_{1,t}}{\partial w_{1,t}^n} + \frac{\partial l_{1,t}}{\partial T_{1,t}} l_{1,t}\right) + \gamma_{t+1} n_{1,t} B_{1,t}\left(\frac{\partial s_{1,t}}{\partial w_{1,t}^n} + \frac{\partial s_{1,t}}{\partial T_{1,t}} l_{1,t}\right) = 0 \qquad \text{(A8)}$$

where $\Omega_{1,t}$ is given by equation (A5), and

$$B_{1,\mathrm{t}} = -\frac{\lambda_t\left(\partial\hat{U}_{2,t}/\partial x_{1,t+1}\right)}{\gamma_{t+1} n_{1,t}}\left(MRS_{1,t}^{c,x} - \widehat{MRS}_{2,t}^{c,x}\right) + \frac{1}{\gamma_{t+1}}\left(\frac{\mu_t}{N_t} - MRS_{1,t}^{c,x}\frac{\mu_{t+1}}{N_{t+1}}\right).$$

Using equation (A5) in equation (A8) and solving for $\tau_{1,t}$ gives equation (20) for the low-ability type. The marginal labor income tax implemented for the high-ability type can be derived in exactly the same way by using equations (A3e), (A3f), and (A3h) together with the additional restriction $r_t - r_{2,t+1}^n$=0.■

Proof of Proposition 3

By using $\theta_t^s = 0$, the first order condition for $\bar{c}_t$ can be written as

$$\begin{aligned}
0 = \frac{\partial\mathcal{L}}{\partial\bar{c}_t} &= -\left(n_{1,t}\frac{\partial U_{1,t}}{\partial\Delta_{1,t}^c} + (n_{2,t} + \lambda_t)\frac{\partial U_{2,t}}{\partial\Delta_{2,t}^c} - \lambda_t\frac{\partial\hat{U}_{2,t}}{\partial\Delta_{1,t}^c}\right) \\
&- \left(n_{1,t-1}\frac{\partial U_{1,t-1}}{\partial\Delta_{1,t}^x} + (n_{2,t-1} + \lambda_{t-1})\frac{\partial U_{2,t-1}}{\partial\Delta_{2,t}^x} - \lambda_{t-1}\frac{\partial\hat{U}_{2,t-1}}{\partial\Delta_{1,t}^x}\right) \\
&+\mu_t\left(1 - \frac{n_{1,t}}{N_t}\frac{\partial c_{1,t}}{\partial\bar{c}_t} - \frac{n_{2,t}}{N_t}\frac{\partial c_{2,t}}{\partial\bar{c}_t} - \frac{n_{1,t-1}}{N_t}\frac{\partial x_{1,t}}{\partial\bar{c}_t} - \frac{n_{2,t-1}}{N_t}\frac{\partial x_{2,t}}{\partial\bar{c}_t}\right) \\
&-\mu_{t-1}\left(\frac{n_{1,t-1}}{N_{t-1}}\frac{\partial c_{1,t-1}}{\partial\bar{c}_t} + \frac{n_{2,t-1}}{N_{t-1}}\frac{\partial c_{2,t-1}}{\partial\bar{c}_t}\right) - \mu_{t+1}\left(\frac{n_{1,t}}{N_{t+1}}\frac{\partial x_{1,t+1}}{\partial\bar{c}_t} + \frac{n_{2,t}}{N_{t+1}}\frac{\partial x_{2,t+1}}{\partial\bar{c}_t}\right) \\
&+\gamma_t\left[n_{1,t}\left(w_{1,t} - w_{1,t}^n\right)\frac{\partial l_{1,t}}{\partial\bar{c}_t} + n_{2,t}\left(w_{2,t} - w_{2,t}^n\right)\frac{\partial l_{2,t}}{\partial\bar{c}_t}\right] \\
&+\gamma_{t-1}\left[n_{1,t-1}\left(w_{1,t-1} - w_{1,t-1}^n\right)\frac{\partial l_{1,t-1}}{\partial\bar{c}_t} + n_{2,t-1}\left(w_{2,t-1} - w_{2,t-1}^n\right)\frac{\partial l_{2,t-1}}{\partial\bar{c}_t}\right] \\
&-\lambda_t\left[w_{1,t}^n\left(\frac{\partial\hat{U}_{2,t}}{\partial c_{1,t}} + \frac{\partial\hat{U}_{2,t}}{\partial\Delta_{1,t}^c}\right) - \phi\frac{\partial\hat{U}_{2,t}}{\partial\hat{z}_{1,t}}\right]\frac{\partial l_{1,t}}{\partial\bar{c}_t} \\
&-\lambda_{t-1}\left[w_{1,t-1}^n\left(\frac{\partial\hat{U}_{2,t-1}}{\partial c_{1,t-1}} + \frac{\partial\hat{U}_{2,t-1}}{\partial\Delta_{1,t-1}^c}\right) - \phi\frac{\partial\hat{U}_{2,t-1}}{\partial\hat{z}_{1,t-1}}\right]\frac{\partial l_{1,t-1}}{\partial\bar{c}_t}
\end{aligned}$$

$$-\lambda_t\left[(1+r^n_{1,t+1})\left(\frac{\partial \hat{U}_{2,t}}{\partial x_{1,t+1}}+\frac{\partial \hat{U}_{2,t}}{\partial \Delta^x_{1,t+1}}\right)-\left(\frac{\partial \hat{U}_{2,t}}{\partial c_{1,t}}+\frac{\partial \hat{U}_{2,t}}{\partial \Delta^c_{1,t}}\right)\right]\frac{\partial s_{1,t}}{\partial \bar{c}_t}$$

$$-\lambda_{t-1}\left[(1+r^n_{1,t})\left(\frac{\partial \hat{U}_{2,t-1}}{\partial x_{1,t}}+\frac{\partial \hat{U}_{2,t-1}}{\partial \Delta^x_{1,t}}\right)-\left(\frac{\partial \hat{U}_{2,t-1}}{\partial c_{1,t-1}}+\frac{\partial \hat{U}_{2,t-1}}{\partial \Delta^c_{1,t-1}}\right)\right]\frac{\partial s_{1,t-1}}{\partial \bar{c}_t}. \quad \text{(A9)}$$

In equation (A9), we have used the short notations $\partial c_{i,t-j}/\partial \bar{c}_t = w^n_{i,t-j}(\partial l_{i,t-j}/\partial \bar{c}_t) - \partial s_{i,t-j}/\partial \bar{c}_t$ and $\partial x_{i,t+j}/\partial \bar{c}_t = (1+r^n_{i,t+j})(\partial s_{i,t-1-j}/\partial \bar{c}_t)$ for i=1,2 and j=0,1.

Next, multiply the right hand side of equation (A3b) by $\alpha^c_{1,t}$ and the right hand side of equation (A3f) by $\alpha^c_{2,t}$. Also, evaluate equations (A3d) and (A3h) for generation t-1, and then multiply by $\alpha^x_{1,t}$ and $\alpha^x_{2,t}$, respectively. This gives

$$0=\frac{\partial \mathcal{L}}{\partial T_{1,t}}\alpha^c_{1,t} = -n_{1,t}\left[\left(\frac{\partial U_{1,t}}{\partial c_{1,t}}+\frac{\partial U_{1,t}}{\partial \Delta^c_{1,t}}\right)-\gamma_t\right]\alpha^c_{1,t}+\gamma_t n_{1,t}\left(w_{1,t}-w^n_{1,t}\right)\frac{\partial l_{1,t}}{\partial T_{1,t}}\alpha^c_{1,t}$$

$$+\gamma_{t+1}n_{1,t}\left(r_{t+1}-r^n_{1,t+1}\right)\frac{\partial s_{1,t}}{\partial T_{1,t}}\alpha^c_{1,t}-\mu_t\frac{n_{1,t}}{N_t}\frac{\partial c_{1,t}}{\partial T_{1,t}}\alpha^c_{1,t}-\mu_{t+1}\frac{n_{1,t}}{N_{t+1}}\frac{\partial x_{1,t+1}}{\partial T_{1,t}}\alpha^c_{1,t}$$

$$-\lambda_t\left[-\left(\frac{\partial \hat{U}_{2,t}}{\partial c_{1,t}}+\frac{\partial \hat{U}_{2,t}}{\partial \Delta^c_{1,t}}\right)+\left\{w^n_{1t}\left(\frac{\partial \hat{U}_{2,t}}{\partial c_{1,t}}+\frac{\partial \hat{U}_{2,t}}{\partial \Delta^c_{1,t}}\right)-\phi\frac{\partial \hat{U}_{2,t}}{\partial \hat{z}_{1,t}}\right\}\frac{\partial l_{1,t}}{\partial T_{1,t}}\right]\alpha^c_{1,t}$$

$$-\lambda_t\left[\left(1+r^n_{1,t+1}\right)\left(\frac{\partial \hat{U}_{2,t}}{\partial x_{1,t+1}}+\frac{\partial \hat{U}_{2,t}}{\partial \Delta^x_{1,t+1}}\right)-\left(\frac{\partial \hat{U}_{2,t}}{\partial c_{1,t}}+\frac{\partial \hat{U}_{2,t}}{\partial \Delta^c_{1,t}}\right)\right]\frac{\partial s_{1,t}}{\partial T_{1,t}}\alpha^c_{1,t} \quad \text{(A10a)}$$

$$0=\frac{\partial \mathcal{L}}{\partial T_{2,t}}\alpha^c_{2,t} = -\left[(n_{2,t}+\lambda_t)\left(\frac{\partial U_{2,t}}{\partial c_{2,t}}+\frac{\partial U_{2,t}}{\partial \Delta^c_{2,t}}\right)-\gamma_t\right]\alpha^c_{2,t}+\gamma_t n_{2,t}\left(w_{2,t}-w^n_{2,t}\right)\frac{\partial l_{2,t}}{\partial T_{2,t}}\alpha^c_{2,t}$$

$$+\gamma_{t+1}n_{2,t}\left(r_{t+1}-r^n_{2,t+1}\right)\frac{\partial s_{2,t}}{\partial T_{2,t}}\alpha^c_{2,t}-\mu_t\frac{n_{2,t}}{N_t}\frac{\partial c_{2,t}}{\partial T_{2,t}}\alpha^c_{2,t}$$

$$-\mu_{t+1}\frac{n_{2,t}}{N_{t+1}}\frac{\partial x_{2,t+1}}{\partial T_{2,t}}\alpha^c_{2,t} \quad \text{(A10b)}$$

$$0=\frac{\partial \mathcal{L}}{\partial \Phi_{1,t}}\alpha^x_{1,t} = -n_{1,t-1}\left[\left(\frac{\partial U_{1,t-1}}{\partial x_{1,t}}+\frac{\partial U_{1,t-1}}{\partial \Delta^x_{1,t}}\right)-\gamma_t\right]\alpha^x_{1,t}$$

$$+\gamma_{t-1}n_{1,t-1}\left(w_{1,t-1}-w^n_{1,t-1}\right)\frac{\partial l_{1,t-1}}{\partial \Phi_{1,t}}\alpha^x_{1,t}$$

$$+\gamma_t n_{1,t-1}\left(r_t-r^n_{1,t}\right)\frac{\partial s_{1,t-1}}{\partial \Phi_{1,t}}\alpha^x_{1,t}-\mu_{t-1}\frac{n_{1,t-1}}{N_{t-1}}\frac{\partial c_{1,t-1}}{\partial \Phi_{1,t}}\alpha^x_{1,t}-\mu_t\frac{n_{1,t-1}}{N_t}\frac{\partial x_{1,t}}{\partial \Phi_{1,t}}\alpha^x_{1,t}$$

$$-\lambda_{t-1}\left[\left\{w^n_{1,t-1}\left(\frac{\partial \hat{U}_{2,t-1}}{\partial c_{1,t-1}}+\frac{\partial \hat{U}_{2,t-1}}{\partial \Delta^c_{1,t-1}}\right)-\phi\frac{\partial \hat{U}_{2,t-1}}{\partial \hat{z}_{1,t-1}}\right\}\frac{\partial l_{1,t-1}}{\partial \Phi_{1,t}}-\left(\frac{\partial \hat{U}_{2,t-1}}{\partial x_{1,t}}+\frac{\partial \hat{U}_{2,t-1}}{\partial \Delta^x_{1,t}}\right)\right]\alpha^x_{1,t}$$

$$-\lambda_{t-1}\left[\left(1+r^n_{1,t}\right)\left(\frac{\partial \hat{U}_{2,t-1}}{\partial x_{1,t}}+\frac{\partial \hat{U}_{2,t-1}}{\partial \Delta^x_{1,t}}\right)-\left(\frac{\partial \hat{U}_{2,t-1}}{\partial c_{1,t-1}}+\frac{\partial \hat{U}_{2,t-1}}{\partial \Delta^c_{1,t-1}}\right)\right]\frac{\partial s_{1,t-1}}{\partial \Phi_{1,t}}\alpha^x_{1,t}. \quad \text{(A10c)}$$

$$0=\frac{\partial\mathcal{L}}{\partial\Phi_{2,t}}\alpha_{2,t}^{x}=-\left[(n_{2,t-1}+\lambda_{t-1})\left(\frac{\partial U_{2,t-1}}{\partial x_{2,t}}+\frac{\partial U_{2,t-1}}{\partial\Delta_{2,t}^{x}}\right)-n_{2,t-1}\gamma_{t}\right]\alpha_{2,t}^{x}$$

$$+\gamma_{t-1}n_{2,t-1}\left(w_{2,t-1}-w_{2,t-1}^{n}\right)\frac{\partial l_{2,t-1}}{\partial\Phi_{2,t}}\alpha_{2,t}^{x}+\gamma_{t}n_{2,t-1}\left(r_{t}-r_{2,t}^{n}\right)\frac{\partial s_{2,t-1}}{\partial\Phi_{2,t}}\alpha_{2,t}^{x}$$

$$-\mu_{t-1}\frac{n_{2,t-1}}{N_{t-1}}\frac{\partial c_{2,t-1}}{\partial\Phi_{2,t}}-\mu_{t}\frac{n_{2,t-1}}{N_{t}}\frac{\partial x_{2,t}}{\partial\Phi_{2,t}}\alpha_{2,t}^{x}. \qquad \text{(A10d)}$$

Subtracting equation (A10a)-(A10d) from equation (A9), and then using the degrees of positionality in equation (3) such that

$$\frac{\partial u_{i,t}}{\partial\Delta_{i,t}^{c}}=\alpha_{i,t}^{c}\left(\frac{\partial u_{i,t}}{\partial c_{i,t}}+\frac{\partial u_{i,t}}{\partial\Delta_{i,t}^{c}}\right)\quad\text{and}\quad\frac{\partial u_{i,t}}{\partial\Delta_{i,t}^{x}}=\alpha_{i,t}^{x}\left(\frac{\partial u_{i,t-1}}{\partial x_{i,t}}+\frac{\partial u_{i,t-1}}{\partial\Delta_{i,t}^{x}}\right)\quad\text{for } i=1,2,$$

we obtain

$$0=\frac{\partial\mathcal{L}}{\partial\bar{c}_{t}}=\mu_{t}\left(1-\frac{\left(n_{1,t}\alpha_{1,t}^{c}+n_{2,t}\alpha_{2,t}^{c}+n_{1,t-1}\alpha_{1,t}^{x}+n_{2,t-1}\alpha_{2,t}^{x}\right)}{N_{t}}\right)$$

$$-\gamma_{t}\left(n_{1,t}\alpha_{1,t}^{c}+n_{2,t}\alpha_{2,t}^{c}+n_{1,t-1}\alpha_{1,t}^{x}+n_{2,t-1}\alpha_{2,t}^{x}\right)$$

$$+\lambda_{t}\left(\frac{\partial\widehat{U}_{2,t}}{\partial c_{1,t}}+\frac{\partial\widehat{U}_{2,t}}{\partial\Delta_{1,t}^{c}}\right)\left(\hat{\alpha}_{2,t}^{c}-\alpha_{1,t}^{c}\right)+\lambda_{t-1}\left(\frac{\partial\widehat{U}_{2,t-1}}{\partial x_{1,t}}+\frac{\partial\widehat{U}_{2,t-1}}{\partial\Delta_{1,t}^{x}}\right)\left(\hat{\alpha}_{2,t}^{x}-\alpha_{1,t}^{x}\right)$$

$$+\left[\gamma_{t}n_{1,t}\left(w_{1,t}-w_{1,t}^{n}\right)-\mu_{t}\frac{n_{1,t}}{N_{t}}w_{1,t}^{n}\right]\left(\frac{\partial l_{1,t}}{\partial\bar{c}_{t}}-\alpha_{1,t}^{c}\frac{\partial l_{1,t}}{\partial T_{1,t}}\right)$$

$$-\lambda_{t}\left[w_{1,t}^{n}\left(\frac{\partial\widehat{U}_{2,t}}{\partial c_{1,t}}+\frac{\partial\widehat{U}_{2,t}}{\partial\Delta_{1,t}^{c}}\right)-\phi\frac{\partial\widehat{U}_{2,t}}{\partial\hat{z}_{1,t}}\right]\left(\frac{\partial l_{1,t}}{\partial\bar{c}_{t}}-\alpha_{1,t}^{c}\frac{\partial l_{1,t}}{\partial T_{1,t}}\right)$$

$$+\left[\gamma_{t}n_{2,t}\left(w_{2,t}-w_{2,t}^{n}\right)-\mu_{t}\frac{n_{2,t}}{N_{t}}w_{2,t}^{n}\right]\left(\frac{\partial l_{2,t}}{\partial\bar{c}_{t}}-\alpha_{2,t}^{c}\frac{\partial l_{2,t}}{\partial T_{2,t}}\right)$$

$$+\left[\gamma_{t-1}n_{1,t-1}\left(w_{1,t-1}-w_{1,t-1}^{n}\right)-\mu_{t-1}\frac{n_{1,t-1}}{N_{t-1}}w_{1,t-1}^{n}\right]\left(\frac{\partial l_{1,t-1}}{\partial\bar{c}_{t}}-\alpha_{1,t}^{x}\frac{\partial l_{1,t-1}}{\partial\Phi_{1,t}}\right)$$

$$-\lambda_{t-1}\left[w_{1,t-1}^{n}\left(\frac{\partial\widehat{U}_{2,t-1}}{\partial c_{1,t-1}}+\frac{\partial\widehat{U}_{2,t-1}}{\partial\Delta_{1,t-1}^{c}}\right)-\phi\frac{\partial\widehat{U}_{2,t-1}}{\partial\hat{z}_{1,t-1}}\right]\left(\frac{\partial l_{1,t-1}}{\partial\bar{c}_{t}}-\alpha_{1,t}^{x}\frac{\partial l_{1,t-1}}{\partial\Phi_{1,t}}\right)$$

$$+\left[\gamma_{t-1}n_{2,t-1}\left(w_{2,t-1}-w_{2,t-1}^{n}\right)-\mu_{t-1}\frac{n_{2,t-1}}{N_{t-1}}w_{2,t-1}^{n}\right]\left(\frac{\partial l_{2,t-1}}{\partial\bar{c}_{t}}-\alpha_{2,t}^{x}\frac{\partial l_{2,t-1}}{\partial\Phi_{2,t}}\right)$$

$$\left[\mu_{t}\frac{n_{1,t}}{N_{t}}-\mu_{t+1}\frac{n_{1,t}}{N_{t+1}}(1+r_{1,t+1}^{n})\right]\left(\frac{\partial s_{1,t}}{\partial\bar{c}_{t}}-\alpha_{1,t}^{c}\frac{\partial s_{1,t}}{\partial T_{1,t}}\right)$$

$$-\lambda_{t}\left[(1+r_{1,t+1}^{n})\left(\frac{\partial\widehat{U}_{2,t}}{\partial x_{1,t+1}}+\frac{\partial\widehat{U}_{2,t}}{\partial\Delta_{1,t+1}^{x}}\right)-\left(\frac{\partial\widehat{U}_{2,t}}{\partial c_{1,t}}+\frac{\partial\widehat{U}_{2,t}}{\partial\Delta_{1,t}^{c}}\right)\right]\left(\frac{\partial s_{1,t}}{\partial\bar{c}_{t}}-\alpha_{1,t}^{c}\frac{\partial s_{1,t}}{\partial T_{1,t}}\right)$$

$$\left[\mu_t \frac{n_{2,t}}{N_t} - \mu_{t+1}\frac{n_{2,t}}{N_{t+1}}(1+r^n_{2,t+1})\right]\left(\frac{\partial s_{2,t}}{\partial \bar{c}_t} - \alpha^c_{2,t}\frac{\partial s_{2,t}}{\partial T_{2,t}}\right)$$

$$\left[\mu_{t-1} \frac{n_{1,t-1}}{N_{t-1}} - \mu_t\frac{n_{1,t-1}}{N_t}(1+r^n_{1,t})\right]\left(\frac{\partial s_{1,t-1}}{\partial \bar{c}_t} - \alpha^x_{1,t}\frac{\partial s_{1,t-1}}{\partial \Phi_{1,t}}\right)$$

$$-\lambda_{t-1}\left[(1+r^n_{1,t})\left(\frac{\partial \widehat{U}_{2,t-1}}{\partial x_{1,t}} + \frac{\partial \widehat{U}_{2,t-1}}{\partial \Delta^x_{1,t}}\right) - \left(\frac{\partial \widehat{U}_{2,t-1}}{\partial c_{1,t-1}} + \frac{\partial \widehat{U}_{2,t-1}}{\partial \Delta^c_{1,t-1}}\right)\right]\left(\frac{\partial s_{1,t-1}}{\partial \bar{c}_t} - \alpha^x_{1,t}\frac{\partial s_{1,t-1}}{\partial \Phi_{1,t}}\right)$$

$$+\left[\mu_{t-1} \frac{n_{2,t-1}}{N_{t-1}} - \mu_t\frac{n_{2,t-1}}{N_t}(1+r^n_{2,t})\right]\left(\frac{\partial s_{2,t-1}}{\partial \bar{c}_t} - \alpha^x_{2,t}\frac{\partial s_{2,t-1}}{\partial \Phi_{2,t}}\right). \quad \text{(A11)}$$

Finally, collecting terms and using the definitions of $\tau^*_{i,t}$, $\theta^*_{i,t+1}$, $\tau^*_{i,t-1}$, and $\theta^*_{i,t}$ in equations (18) and (19) to calculate $\Delta\tau_{i,t} = \tau_{i,t} - \tau^*_{i,t}$, $\Delta\theta_{i,t+1} = \theta_{i,t+1} - \theta^*_{i,t+1} = -\theta^*_{i,t+1}$, $\Delta\tau_{i,t-1} = \tau_{i,t-1} - \tau^*_{i,t-1}$, and $\Delta\theta_{i,t} = \theta_{i,t} - \theta^*_{i,t} = -\theta^*_{i,t}$ gives equation (21).■

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