Taxing capital is not a bad idea indeed: the role of human capital and labor-market frictions

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Abstract: In a second-best optimal growth setup with only factor taxes as available instruments, is it optimal to *fully* replace capital by labor income taxation? The answer is generally positive based on Chamley, Judd, Lucas, and many follow-up studies. In the present paper, we revisit this important tax reform-related issue by developing a human capital-based endogenous growth framework with frictional labor search and matching. We allow each firm to create multiple vacancies and each worker to determine labor market participation endogenously. We consider a benevolent fiscal authority to finance direct transfers to households and unemployment compensation only by factor taxes. We then conduct dynamic tax incidence exercises using a model calibrated to the U.S. economy with a pre-existing 20% flat tax on both the capital and labor income. Our numerical results suggest that, due to a dominant channel via the interactions between the firm's vacancy creation and the worker's market participation, it is optimal to switch *partly* by a modest margin from capital to labor taxation in a benchmark economy where human capital formation depends on both the physical and human capital stocks. When the human capital accumulation process is independent of physical capital, the optimal tax mix features a slightly larger shift from capital to labor taxation; when we remove the extensive margin of the labor-leisure trade-off, such a shift is much larger. In either case, however, the optimal capital tax rate is far above zero.

JEL Classification: E62, H22, O4, J2.

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1 Introduction

Since the pivotal work by Chamley (1985a, 1985b, 1986) and Judd (1985, 1987), there has been a large literature studying dynamic factor tax incidence in optimal growth models in order to identify the optimal factor tax mix in a second-best world where full access to the lump-sum tax is unavailable. Because labor is fixed but capital can be accumulated over time, Chamley and Judd recommended that the optimal flat factor tax scheme be implemented to fully eliminate the tax on the more elastic capital and to impose a tax only on the perfectly inelastic labor in the long run. This Chamley-Judd proposition has been revisited and extended to various economic environments and the general conclusion has largely been robust as long as the flat factor tax rate setup and the benevolent central planner assumption are maintained.

About two decades ago, the celebrated work by Lucas (1988) provided a compelling argument that human capital is a primary engine of the endogenously determined economy-wide growth rate. Because human capital augments labor, an immediate question arose: Would it be welfare-reducing to tax labor in a human capital-based endogenous growth framework? Two years later, Lucas (1990) himself addressed this question based on his dynamic factor tax incidence exercises and provided a policy recommendation that neither physical nor human capital should be taxed and that only raw labor should be taxed. His policy recommendation has not yet been challenged in a prototypical setup with flat factor tax rates and a benevolent central planner.

In this paper, we follow this convention by reexamining the validity of the Lucasian policy recommendation in a generalized human capital-based endogenous growth economy with individuals endogenously participating in the frictional labor market. It was well-documented in the labor search literature pioneered by Mortensen (1982) and Pissarides (1984) that informational and institutional barriers to job search, employee recruiting, and vacancy creation were substantial. Such frictions have been shown to generate important impacts on macroeconomic performance over the business cycle (cf. Mortensen and Pissarides 1994; Merz 1995; Andolfatto 1996) as well as in the long run (cf. Aghion and Howitt 1994; Laing, Palivos and Wang 1995; Chen, Chen and Wang 2011).[1] It is therefore natural to inquire whether such frictions may influence individual decisions to generate sufficient "responsiveness" in the long run to a tax on labor income such that labor taxation is too distortionary to be used to fully replace capital taxation.

Our paper attempts to address this important issue that has practically valuable implications for tax reform considerations. Specifically, we construct a two-sector human capital-based endogenous growth framework with labor market search and entry frictions in which the labor market participation decision is endogenous. We assume that vacancy creation and maintenance as well as job search are all costly and that unfilled vacancies and active job seekers are brought together by a

[1] See Rogerson, Shimer and Wright (2005) for a comprehensive survey.

matching technology exhibiting constant returns. We consider "large" firms and "large" households where each firm creates and maintains multiple vacancies and each household contains a continuum of members comprising employed and nonemployed workers. The wage rate (in efficiency units) is determined based on a cooperative bargain between the matched firm and household pair, satisfying the Hosios (1990) rule of bargaining efficiency. A benevolent fiscal authority finances direct transfers to households and unemployment compensation only by way of taxing factor incomes. In the benchmark setup, we consider a general two-sector framework as proposed by Bond, Wang and Yip (1996) in which the accumulation of either physical or human capital is driven by both physical and human capital stocks. We then consider another type of economy with a Lucasian human capital accumulation process that is independent of physical capital. We further calibrate our economy to fit observations in the U.S. over the post-WWII period, with a pre-existing 20% flat tax rate being levied on both capital and labor income. This enables us to conduct dynamic factor tax incidence exercises, and to draw policy recommendations based on a revenue-neutral welfare comparison of factor taxes.

Our main findings can be summarized as follows. We show that, under an efficiency wage bargain, both capital and labor taxes lower the bargained wage rate (in efficiency units). However, these factor taxes can generate very different effects on the wage discount that measures how much our equilibrium wage in the presence of labor market search and entry frictions is below the competitive counterpart in a frictionless Walrasian setup. Specifically, under an efficiency wage bargain, if the capital tax rate is initially too low, then a higher tax on capital income accompanied by a revenue-neutral reduction in the labor tax turns out to raise the wage discount and to encourage firms to create more vacancies. This in turn raises the job finding rate and hence induces workers to more actively participate in the labor market to seek employment. Because this leads to positive effects on employment and output growth, a shift from a zero to a positive capital tax rate becomes welfare-improving, thereby yielding a policy recommendation different from that of Chamley-Judd-Lucas.

By conducting factor tax incidence exercises in our calibrated economy, we find that, in the benchmark case with factor taxes at pre-existing rates of $(20\%, 20\%)$, it is optimal to only partly replace the capital tax by the labor tax: the optimal flat tax rates on capital and labor income are 19.07% and 24.56%, respectively. Since the above-mentioned vacancy creation-labor participation channel is quantitatively significant, the optimal factor tax rates turn out to be close to their pre-existing figures. As a consequence, such a reform only induces a modest 0.0128% welfare gain in consumption equivalence. Upon various sensitivity and robustness checks, we find that it is hardly optimal to fully replace capital by labor taxation within all reasonable ranges of parameterization. The conclusion remains even when the extensive margin of leisure is shut down and when the human capital accumulation process is independent of physical capital. When the human capital accumulation process is independent of physical capital, the optimal tax rates on capital and labor income become 17.87% and 30.70%, respectively, featuring a slightly larger shift from capital to labor taxation. When we remove the extensive margin of the labor-leisure trade-off, such a shift is much larger: the optimal tax rates on capital and labor income are now 9.15% and 68.79%, respectively. The results suggest that while the vacancy creation-labor participation channel and the extensive margin of the labor-leisure trade-off are quantitatively crucial for dynamic factor tax incidence, the form of human capital accumulation is not. Finally, in an economy with a Lucas (1988)-type human capital accumulation process, independent of physical capital, or with a Walrasian frictionless labor market, it is always optimal to fully eliminate capital taxation by taxing only labor income.

Related Literature

Our paper is related to the discrete-time, real-business-cycle (RBC) search literature pioneered by Merz (1995) and Andolfatto (1996). In contrast with theirs, our model considers sustained economic growth with endogenous human capital accumulation. Previously, Laing, Palivos and Wang (1995) incorporated human capital-based endogenous growth into the Mortensen-Pissarides search framework, whereas Chen, Chen and Wang (2011) introduced human capital growth into the Andolfatto-Merz RBC search framework using a pseudo central planning setup. We follow the latter strategy, allowing comprehensive labor-leisure-learning-search trade-offs as well as endogenous labor-market participation. Differing from their work, our paper performs dynamic factor tax incidence analysis in a fully decentralized setup with a more general human capital accumulation process.

Over the past two decades, several studies have investigated the long-run growth effects of factor taxes, including King and Rebelo (1990), Stokey and Rebelo (1995), Bond, Wang and Yip (1996), and Mino (1996), under perfectly competitive setups without externalities. This literature has been extended to incorporate positive externalities, productive public capital or market imperfections, such as Guo and Lansing (1999), Cassou and Lansing (2006) and Chen (2007). This strand of the literature, however, focuses exclusively on long-run growth or welfare effects of factor taxation rather than on factor tax incidence.

The closely related literature was initiated by Lucas (1990) who reexamined the Chamley-Judd proposition of dynamic factor tax incidence in a human capital-based endogenous growth framework.[2] His main conclusion was that the government should not tax either physical or human capital but rather tax raw labor only. This Lucasian policy recommendation was reconfirmed by Jones, Manuelli and Rossi (1993) in which only investment goods enter physical and human capital accumulation (i.e., there is no trade-off between education time and work hours). Even in a more general setup by Jones, Manuelli and Rossi (1997) that allowed both investment goods and education time to enter human capital accumulation, the Lucasian policy recommendation still remains valid

[2] There is a recent strand of the literature on optimal taxation which does not incorporate human capital, but instead considers nonlinear labor taxation, alternative non-factor taxes, incentive problems and/or political economy. Its focus is very different from ours.

under constant-returns technologies in the absence of an alternative tax on consumption.

In a recent paper, Conesa, Kitao and Krueger (2009) pointed out clearly that a call for taxing capital may be due to borrowing constraints, uninsurable idiosyncratic income risk, and/or life-cycle settings where the tax code cannot be age-dependent. In their paper, these aforementioned features as well as the progressiveness of labor income taxes are all allowed. Yet, in their calibrated model M1 where borrowing constraints, idiosyncratic risk and progressive tax features are turned off, the optimal factor tax mix is to levy 10% and 19% tax rates, respectively, on capital and labor income (with consumption being taxed at 5%).[3] The positive capital tax prescription in this simple setup is purely a consequence of the life-cycle setting: assuming a period-by-period balanced government budget, capital taxation serves to equate aggregate private asset demand with the society's capital stock in the presence of life-cycle competitive inefficiency. Capital income becomes essentially tax-exempt when life-cycle competitive inefficiency is largely mitigated by a nontrivial age-dependent wage earning profile and a pay-as-you-go social security system. In our infinite lifetime model, such life-cycle competitive inefficiency is absent. Yet, by incorporating endogenous human capital accumulation together with endogenous participation in a frictional labor market, we still establish that "taxing capital is not a bad idea after all" based on very different underlying economic channels from Conesa, Kitao and Krueger.

2 The Model

We consider a discrete-time model with a continuum of identical infinitely-lived large firms (of measure one), a continuum of identical infinitely-lived large households (of measure one) and a fiscal authority.

The adoption of the large household setup proposed by Lucas (1990) is to ease unnecessary complexity involved in tracking the distribution of the employed and the unemployed, so as to eliminate the possibility of an endogenous distribution of human and physical capital stocks as a result of idiosyncratic search and matching risk in the frictional labor market. The large household consists of a continuum of members (of measure one), who are either (i) employed, by engaging in production, on-the-job learning, or leisure activity, or (ii) nonemployed, by engaging in job seeking or leisure activity. We assume that households own both productive factors, capital and labor.

While the goods market is Walrasian and the capital market is perfect, the labor market exhibits search and entry frictions. In particular, a firm can create and maintain (multiple) vacancies only upon paying a vacancy creation and maintenance cost in the form of labor inputs. The household's (endogenously determined) labor market participation is also costly with a foregone earning cost.

[3]By allowing for endogenous learning-by-doing, Peterman (2010) obtains optimal capital and labor tax rates of 21% and 23%, respectively.

Unfilled vacancies and active job seekers are brought together through a Diamond (1982) type of matching technology, where each vacancy can be filled by exactly one searching worker. In our model, the flow matching rates (job finding and employee recruitment rates) are both endogenous, depending on the masses of both matching parties. In every period, filled vacancies and employed workers are separated at an exogenous rate.

The benevolent fiscal authority's behavior is simple: it uses factor taxes to finance direct transfers to households and unemployment compensation. The optimal factor tax mix is to maximize social welfare by maintaining a periodically balanced budget.

2.1 Households

The economy is populated with a continuum of large households of mass one, each consisting of a continuum of members of unit mass. A representative large household with a unified preference pools all resources and enjoyment from its members. In period t, a fraction n_t of the members are employed and $1 - n_t$ are nonemployed. To simplify the analysis, let each member be endowed with one unit of "day" time and z unit of "night" time. While the night time is for leisure purposes, the one unit of day time endowed by an employed member can be freely allocated to production (work effort, denoted ℓ_t) or to human capital investment (learning effort, denoted $1 - \ell_t$). By contrast, the nonemployed allocates the entire time endowment $1 + z$ to leisure. The allocation of labor in the day time is delineated in Figure 1. The unemployment rate is simply $u_t = 1 - n_t$. In addition to the labor endowment, households are assumed to own the entire stock of physical capital k_t.

Since job matches are not instantaneous, the level of employment from the household's perspective is given by the following birth-death process,

$$n_{t+1} = (1 - \psi)n_t + \mu_t(1 - n_t) \tag{1}$$

where ψ denotes the (exogenous) job separation rate and μ_t is the (endogenous) job finding rate. That is, the change in employment $(n_{t+1} - n_t)$ is equal to the inflow of workers into the employment pool $(\mu_t(1 - n_t))$ net of the outflow as a result of separation (ψn_t).

We consider a general human capital accumulation technology proposed by Bond, Wang and Yip (1996) in which the production of incremental human capital requires both human and physical capital inputs. Denote the fraction of physical capital devoted to goods production as s_t and that to human capital accumulation as $1 - s_t$. The aggregate human capital of the household can thus be accumulated via learning by the employed and inputs of the market good – physical capital:

$$h_{t+1} - h_t = Dn_t(1 - \ell_t)h_t + \widetilde{D}[(1 - s_t)k_t]^{\gamma}[n_t(1 - \ell_t)h_t]^{1-\gamma} \tag{2}$$

where $h_0 > 0$ is exogenously given, $\gamma \in (0, 1)$ and $D, \widetilde{D} > 0$. When $\widetilde{D} = 0$ (and $s = 1$), human capital accumulation is independent of market goods. This linear human capital evolution process resembles that proposed by Lucas (1988): it reduces to the Lucasian setup when $n_t = 1$. Since the accumulation of human capital depends on the employment rate n_t, it gives the flavor of on-the-job learning. The above setup implies that the unemployed cannot accumulate human capital, or, more generally, their human capital accumulation is completely offset by their human capital depreciation.[4] In general, $\widetilde{D} > 0$ and the accumulation of human capital requires inputs of market goods. The functional form given above implies that physical capital is not necessary for human capital accumulation as long as $D > 0$.

Denote the effective wage and the capital rental rates by w_t and r_t , respectively, and the labor and capital income tax rates by τ_L and τ_K, respectively. Let c_t be household consumption and δ_k be the physical capital depreciation rate. In addition, denote the ratio of unemployment compensation to the market wage by $\bar{b}$ and the per household lump-sum transfer from the government by T_t. The household faces the following budget constraint:

$$k_{t+1} = (1-\tau_L)w_t h_t \left[n_t \ell_t + (1-n_t)\bar{b}\right] + [(1-\delta_k) + (1-\tau_K)r_t s_t]k_t - c_t + T_t \tag{3}$$

That is, the household allocates the total wage from employed members, total unemployment compensations from unemployed members, total rentals from market capital devoted to production ($s_t k_t$) and total transfers to consumption and gross investment.

Let $\rho > 0$ be the subjective rate of time preference. The representative household's preference takes a standard time-additive form:

$$\Omega = \sum_{t=0}^{\infty} \left(\frac{1}{1+\rho}\right)^t \tilde{U}(c_t, n_t)$$

The periodic utility function is given by $\tilde{U}(c_t, n_t) = U(c_t) + m_1 n_t G(z_1) + m_2 (1-n_t) G(z_2)$, where G is a function of individual leisure time z, taking a standard form with constant elasticity of intertemporal substitution $\epsilon \in (0,1)$: $G(z_i) = \frac{(z_i)^{1-\epsilon^{-1}}}{1-\epsilon^{-1}}$ (e.g., see Andolfatto 1995 and many others in the macro labor literature). In this setup, what is emphasized is the *extensive* margin: the unemployment takes more leisure than the employed. Recall that under our large household setting, the employed devoted one unit of time to work and learning. To the unemployed, this one unit of time becomes leisure. That is, $z_1 = z$ and $z_2 = 1 + z$. In this way, the large household's leisure is endogenous purely due to the extensive margin related to endogenous labor participation. We can rewrite the periodic utility function in a more convenient form:

$$\begin{aligned}
\tilde{U}(c_t, n_t) &= U(c_t) + m_1 n_t G(z) + m_2 (1-n_t) G(1+z) \\
&= U(c_t) + m_2 G(1+z) - [m_2 G(1+z) - m_1 G(z)]\, n_t \\
&= \text{constant} + U(c_t) - m(1-n_t)
\end{aligned}$$

[4] See Jacobson, LaLonde and Sullivan (1993) and Laing, Palivos and Wang (2003) for a further discussion of the human capital depreciation of displaced workers.

where $m \equiv m_2 G(1+z) - m_1 G(z)$.

Let $\mathcal{H} = (k, h, n)$ denote the vector of current period state variables and $\mathcal{H}'$ denote that of the next period state variables. Then, the household's optimization problem can be expressed in Bellman equation form as:

$$\Omega(k_t, h_t, n_t) = \max_{c_t,\, \ell_t,\, s_t} U(c_t) - m(1-n_t) + \frac{1}{1+\rho}\Omega(k_{t+1}, h_{t+1}, n_{t+1}) \tag{4}$$

subject to constraints (1), (2), and (3).

Define conveniently effective capital-labor ratios in the nonmarket and market sectors as $q^H = \frac{(1-s)k}{n(1-\ell)h}$ and $q^F = \frac{sk}{n\ell h}$, respectively. The first-order conditions with respect to c_t, ℓ_t and s_t are given by,[5]

$$U_c = \frac{1}{1+\rho}\Omega_k(\mathcal{H}') \tag{5}$$

$$\Omega_k(\mathcal{H}')(1-\tau_L)w = \Omega_h(\mathcal{H}')\left[D + \widetilde{D}(1-\gamma)\left(q^H\right)^\gamma\right] \tag{6}$$

$$\Omega_k(\mathcal{H}')(1-\tau_K)r = \Omega_h(\mathcal{H}')\widetilde{D}\gamma\left(q^H\right)^{\gamma-1} \tag{7}$$

The Benveniste-Scheinkman conditions are:

$$\Omega_k(\mathcal{H}) = \frac{1}{1+\rho}\Omega_k(\mathcal{H}')[1-\delta_k+(1-\tau_K)rs] \tag{8}$$

$$\Omega_h(\mathcal{H}) = \frac{1}{1+\rho}(\Omega_k(\mathcal{H}')(1\text{-}\tau_L)w[n\ell+(1\text{-}n)\bar{b}]+\Omega_h(\mathcal{H}')\{1+n(1\text{-}\ell)[D+\widetilde{D}(1\text{-}\gamma)\left(q^H\right)^\gamma]\}) \tag{9}$$

$$\Omega_n(\mathcal{H}) = m+\frac{1}{1+\rho}\{\Omega_k(\mathcal{H}')(1\text{-}\tau_L)wh(\ell\text{-}\bar{b})+\Omega_h(\mathcal{H}')(1\text{-}\ell)h[D+\widetilde{D}(1\text{-}\gamma)\left(q^H\right)^\gamma]+\Omega_n(\mathcal{H}')(1\text{-}\psi\text{-}\mu)\} \tag{10}$$

From (6) and (7), we can solve the nonmarket effective capital-labor ratio q^H as a function of the after-tax wage-rental ratio alone:

$$\frac{D + \widetilde{D}(1-\gamma)\left(q^H\right)^\gamma}{\widetilde{D}\gamma\left(q^H\right)^{\gamma-1}} = \frac{(1-\tau_L)w}{(1-\tau_K)r} \tag{11}$$

This positive relationship may be thought of as the relative factor supply schedule.

2.2 Firms

The economy is populated by a continuum of large firms of mass one, each creating and maintaining multiple job vacancies. A representative firm produces a single final good y_t by renting capital k_t from households and employing labor of mass n_t under a constant-returns-to-scale Cobb-Douglas technology,

$$y_t = A\left(s_t k_t\right)^\alpha\left(n_t \ell_t h_t\right)^{1-\alpha} \tag{12}$$

[5] We note that the second-order conditions for the household's and firm's optimization as well as for the bargaining between a household and a firm are rather complex. Thus, while we will check the second-order conditions numerically, we do not report the analytic expressions.

where $A > 0$ and $\alpha \in (0, 1)$.

Denoting η_t as the (endogenous) recruitment rate and v_t as (endogenous) vacancies created, we can specify the level of employment from the firm's perspective as follows:

$$n_{t+1} = (1 - \psi)n_t + \eta_t v_t \tag{13}$$

where the change in employment is equal to the inflow of employees ($\eta_t v_t$) net of the outflow (ψn_t).

To be consistent with a balanced growth equilibrium, we assume that the unit cost of creating and maintaining a vacancy is proportional to the average firm output $\bar{y}_t$. This setup is natural – the more production the economy has, the more firms will compete for resources and the greater the vacancy creation cost will be. Moreover, it is parsimonious – the optimization is simple because $\bar{y}_t$ is regarded as given to each individual firm. Furthermore, it is neutral – the base in which vacancy costs grow is not biased toward one of the two production factor inputs. Thus, the resource cost for vacancy creation and maintenance is given by $\Phi(v_t) = \phi \bar{y}_t v_t$, where $\phi > 0$. The level of employment is the only state variable in the representative firm's optimization problem. Each unit of employment is augmented by the multiple of work effort and human capital, $x_t = \ell_t h_t$. In this endogenous growth framework, both capital stocks grow unboundedly. To ensure the stationarity of the optimization problem (i.e., bounded firm value), we therefore deflate the firm's flow profit $\pi_t = A(s_t k_t)^\alpha (n_t x_t)^{1-\alpha} - w_t n_t x_t - r_t s_t k_t - \phi \bar{y}_t v_t$ by x_t, where x_t measures the "effective productivity" of the state variable, n_t, and is taken as given by the representative firm. The associated Bellman equation can then be written as:

$$\Gamma(n_t) = \max_{v_t,\, k_t} \left\{ A(s_t k_t)^\alpha (n_t x_t)^{1-\alpha} - w_t n_t x_t - r_t s_t k_t - \phi \bar{y}_t v_t \right\} / x_t + \frac{1}{1 + r_t} \Gamma(n_{t+1}) \tag{14}$$

subject to constraint (13).

The first-order conditions with respect to v_t and k_t and the Benveniste-Scheinkman condition are derived as follows:

$$\frac{\eta}{1+r} \Gamma_n (n') = \phi A \left(q^F\right)^\alpha n \tag{15}$$

$$\alpha A \left(q^F\right)^{\alpha - 1} = r \tag{16}$$

$$\Gamma_n(n) = (1 - \alpha) A \left(q^F\right)^\alpha - w + \frac{1 - \psi}{1 + r} \Gamma_n (n') \tag{17}$$

From (16), we can derive the market effective capital-labor ratio q^F as a function of the capital rental rate alone:

$$q^F = \left(\frac{\alpha A}{r} \right)^{\frac{1}{1-\alpha}} \tag{18}$$

which is downward-sloping as expected.

2.3 Labor Matching and Bargaining

While the capital market is assumed to be perfect, the labor market exhibits search frictions. Following Diamond (1982), we assume pair-wise random matching in which the matching technology takes the following constant-returns form:

$$M_t = B(1-n_t)^{\beta}\,(v_t)^{1-\beta} \tag{19}$$

where $B > 0$ measures the degree of matching efficacy and $\beta \in (0,1)$.

In our model economy, the household's surplus accrued from a successful match is measured by its incremental value of supplying an additional worker (Ω_n) whereas the firm's surplus is measured by its incremental value of hiring an additional employee (Γ_n). The representative household and the representative firm determine the effective wage rate through cooperative bargaining to maximize their joint surplus:

$$\max_{w_t}(\Omega_{n_t})^{\zeta}(\Gamma_{n_t})^{1-\zeta}$$

where $\zeta \in (0,1)$ denotes the bargaining share to the household. In solving this wage bargaining problem, the household-firm pair treats matching rates (μ_t and η_t), the beginning-of-period level of employment (n_t), and the market rental rate (r_t) as given. With efficiency bargaining, the Hosios (1990) rule holds in that $\zeta = \beta$. That is, the bargaining share is pinned down by the respective matching elasticity. The first-order condition of the bargaining problem is derived below:

$$\frac{\beta}{w_t}\left(\frac{w_t}{\Omega_{n_t}}\frac{d\Omega_{n_t}}{dw_t}\right) = \frac{1-\beta}{w_t}\left(-\frac{w_t}{\Gamma_{n_t}}\frac{d\Gamma_{n_t}}{dw_t}\right) \tag{20}$$

2.4 The Government

The government's objective is to maximize the social welfare under a balanced budget. Its budget constraint is given by,

$$T_t + w_t h_t(1-n_t)\bar{b} = \tau_L w_t h_t\left[n_t\ell_t + (1-n_t)\bar{b}\right] + \tau_K r_t s_t k_t \tag{21}$$

That is, the government receives wage and capital income taxes to spend on direct transfers to households and unemployment compensation. Of particular note is that the inclusion of transfers is to ensure that the government's budget is balanced in the presence of pre-existing factor taxes and unemployment compensation that fits the data observations.

With a frictional labor market and cooperative bargaining, firms will have none zero flow profit. A direct and convenient measure of social welfare is the balanced-growth "augmented household value," denoted by Λ, in which the household consumption is augmented by the flow profit redistribution (i.e., $c+\pi$).[6] Thus, the dynamic tax incidence problem is to maximize the balanced-growth

[6] We will return to a full specification of this augmented household value after solving the steady-state equilibrium.

augmented household value subject to all the policy functions obtained from the household's and the firm's optimization problems, the bargaining problem, and the government's budget constraint (21).[7]

3 Equilibrium

A *dynamic search equilibrium* is a tuple of individual quantity variables, $\{c_t,\ \ell_t,\ v_t,\ k_t,\ h_t,\ n_t,\ y_t,\ q_t\}_{t=0}^{\infty}$, a pair of aggregate quantities $\{M_t,\ T_t\}_{t=0}^{\infty}$, a pair of matching rates $\{\mu_t,\ \eta_t\}_{t=0}^{\infty}$, and a pair of prices, $\{w_t,\ r_t\}_{t=0}^{\infty}$, such that: (i) all households and firms optimize; (ii) human capital and employment evolution hold, (iii) labor-market matching and wage bargaining conditions are met; (iv) the government budget is balanced; and (v) the goods market clears. A *balanced growth path* (BGP) is a dynamic search equilibrium along which consumption, physical and human capital, and output all grow at positive constant rates. In our model, both the market goods and the human capital investment production technologies are homogeneous of degree one in reproducible factors (k and h). Thus, all endogenously growing quantities (c, k, h and y) must grow at a common rate, g, on a BGP, whereas employment (n), vacancies (v) and equilibrium matches (M) must all be stationary. Given the common growth property, we can divide all the perpetually growing variables by h to obtain stationary ratios, $\frac{k}{h}$, $\frac{c}{h}$, and $\frac{y}{h}$, where the latter two ratios measure effective consumption and effective output, respectively.

Along a BGP, the labor market must satisfy the steady-state matching (Beveridge curve) relationships given by,

$$\psi n = \mu(1-n) = \eta v = B(1-n)^{\beta}\,(v)^{1-\beta} \tag{22}$$

An additional condition to the previously defined employment evolution and labor-market matching equations, (1), (13) and (19), is to require the equilibrium employment inflows from the household side ($\mu(1-n)$) to be equal to those from the firm side (ηv). The above relationships enable us to solve both matching rates and equilibrium vacancies as functions of n alone:

$$\mu(n) = \frac{\psi n}{1-n} \tag{23}$$

[7] It should be noted that the government cannot coordinate labor-market matches (i.e., regard matching rates $\{\mu, \eta\}$ as given); however, it can determine the sharing rule based on efficient bargaining. Thus, the government solves a pseudo planner's dynamic programming problem using the individual's lifetime utility with the resource constraint replacing the household budget constraint, without wage bargaining, to determine optimal flat tax rates (τ_K^*, τ_L^*) by evaluating the outcome at the BGP. Because our decentralized outcome satisfies the efficient-bargain Hosios rule, it is equivalent to solving the above problem as follows: given all individual policy functions, the resource constraint, the government budget constraint and the matching rate *functions* $\{\mu(n), \eta(n)\}$, the government maximizes Λ to determine optimal flat tax rates (τ_K^*, τ_L^*).

$$\eta(n) = B^{\frac{1}{1-\beta}} \mu(n)^{\frac{-\beta}{1-\beta}} \tag{24}$$

$$v(n) = B^{\frac{-1}{1-\beta}} \mu(n)^{\frac{\beta}{1-\beta}} \psi n \tag{25}$$

Thus, while the job finding rate and equilibrium vacancies are positively related to equilibrium employment, the employee recruitment rate is negatively related to it. We can also derive the labor-market tightness measure (from the firm's point of view), $\theta = v/(1-n)$, as:

$$\theta(n) = \left[\frac{\mu(n)}{B}\right]^{\frac{1}{1-\beta}} \tag{26}$$

which is positively related to the job finding rate and hence equilibrium employment.

In order to generate a BGP equilibrium, we must impose a logarithmic utility function: $U(c) = \ln c$.[8] Along a BGP, $\Gamma_n(n')$ and $\Omega_n(\mathcal{H}')$ are constant whereas $\Omega_k(\mathcal{H}')$ and $\Omega_h(\mathcal{H}')$ are decreasing at rate g. From (15), (16) and (17), we obtain an expression for employment that depends on the market effective capital-labor ratio as well as the recruitment rate and the wage rate:

$$n = \frac{\eta}{(r+\psi)\phi}\left[(1-\alpha) - \frac{\alpha w}{r q^F}\right] \tag{27}$$

Using (6), (8), and (9), we obtain:

$$g = \frac{(1-\tau_K) r s - \delta_k - \rho}{1+\rho} \tag{28}$$

$$\rho + (1+\rho) g = \left[D + \widetilde{D}(1-\gamma)\left(q^H\right)^{\gamma}\right][n + (1-n)\bar{b}] \tag{29}$$

The expression (28) is a generalized Keynes-Ramsey relationship governing consumption growth, now depending on the market use of physical capital s. The expression (29) is an intertemporal optimization condition governing human capital accumulation.

Moreover, we can apply the human capital evolution equation (2) to relate learning effort to the nonmarket effective capital-labor ratio, employment and the balanced growth rate:

$$1 - \ell = \frac{g}{n\left[D + \widetilde{D}\left(q^H\right)^{\gamma}\right]} \tag{30}$$

Further define the unit wage income as $S_w = (1-\tau_L)\left[1 + \frac{(1-n)\bar{b}}{n\ell}\right]$ and the unit rental income as $S_r = \left[(1-\tau_K) r - \frac{g+\delta_k}{s}\right]$. From (3) and the definition of q^F, we can derive effective consumption along a BGP as:

$$\frac{c}{h} = \left(S_w w + S_r q^F\right) n\ell + \frac{T}{h} \tag{31}$$

where T is regarded as given by individuals with its equilibrium value being pinned down by the government budget constraint (21).

[8] Suppose the utility function takes a constant elasticity of intertemporal substitution form. It can be easily verified that, should this elasticity be different from one, (10) would violate the BGP requirements.

To solve the wage bargaining problem, we first note that the household-firm pair in the bargaining game must take $\{\mu, \eta, n, r\}$ as given. From (18), q^F must also be regarded as predetermined. Using (11) and (29), we can express both the nonmarket effective capital-labor ratio and the balanced growth rate as increasing functions of the bargained wage alone: $q^H = q^H(w)$ and $g = g(w)$. Intuitively, while it is clear that a higher wage and hence a higher wage-rental ratio (given r) leads to a higher non-market effective capital-output ratio, the latter in turn raises the BGP human capital accumulation rate. Combining (29) and (30) yields $\ell(w)$ as follows:

$$\ell(w) = 1 - \frac{(1-\gamma)g(w)}{n}\left[\frac{(1+\rho)\,g(w)+\rho}{n+(1-n)\bar{b}} - \gamma D\right]^{-1} \tag{32}$$

The bargained wage serves as an incentive to encourage households, on the one hand, to devote more effort to market activity, while, on the other hand, accumulating more human capital. When the long-run human capital accumulation effect dominates (as it will in the calibrated economy), it is expected that an increase in the bargained wage will reduce work effort. By the definitions of q^F and q^H, we have:

$$\frac{q^F}{q^H(w)} = \frac{s}{1-s}\frac{1-\ell(w)}{\ell(w)}$$

which can then be used to derive $s = s(w)$ as a decreasing function of the bargained wage. Intuitively, a higher bargained wage raises the learning effort $(1-\ell)$ and, by capital-labor complementarity, results in a larger fraction of capital being devoted to human capital accumulation (i.e., a higher $1-s$).

Endowed with the functions $q^H(w)$, $g(w)$, $\ell(w)$ and $s(w)$ given above, we are now ready to determine the equilibrium wage. From (8), (9) and (10), we can write the household's surplus accrued from a successful match as follows:

$$\Omega_n = \frac{1+\rho}{\rho+\psi+\mu}\left[(1-\tau_L)(1-\bar{b})\frac{w}{c/h} + m\right] \tag{33}$$

where from (31) $\frac{c}{h}$ is increasing in w but less than proportionally, implying that the household's surplus is increasing in w.

It is informative to compute the wage discount that measures how much the bargained wage is below its competitive counterpart (i.e., the marginal product of labor, MPL):

$$\Delta \equiv \frac{MPL - w}{MPL} = 1 - \frac{w}{(1-\alpha)A\left(q^F\right)^{\alpha}} \tag{34}$$

Straightforward differentiation of the surplus accrued by each party leads to $-\frac{w}{\Gamma_n}\frac{d\Gamma_n}{dw} = \frac{1-\Delta}{\Delta}$ and $\frac{w}{\Omega_n}\frac{d\Omega_n}{dw} = \frac{S_r q^F + T/(n\ell h)}{S_w w + S_r q^F + T/(n\ell h)}$. While the former is decreasing in the wage discount Δ and hence increasing in w, the latter is decreasing in w. Thus, we can rewrite (20) as:

$$MB_w = \frac{\beta}{w + m\frac{(S_w w + S_r q^F)n\ell + T/h}{(1-\tau_L)(1-\bar{b})}}\frac{S_r q^F n\ell + \frac{T}{h}}{\left(S_w w + S_r q^F\right)n\ell + \frac{T}{h}} = \frac{1-\beta}{(1-\alpha)A\left(q^F\right)^{\alpha} - w} = MC_w \tag{35}$$

where the marginal benefit from the household's point of view (MB_w) is decreasing in w and the marginal cost from the firm's point of view (MC_w) is increasing in w (see the top panel of Figure 2).[9] We can also plot the relationship between the wage discount and the wage rate, which is downward-sloping based on the expression in (34) above (see the bottom panel of Figure 2). Once the bargained wage is determined (see w_0 in Figure 2), we can then solve the associated wage discount (see Δ in Figure 2).

Most notably, using (24), (25), (28) and (35) to eliminate q^F, η, v, r, and w, we can then express (27) as a relationship in (n, g). This relationship summarizes a firm's efficiency conditions that govern capital demand, labor demand and vacancy creation, with steady-state matching and bargained wage conditions embedded, which will be referred to as the *equilibrium firm efficiency* (FE) relationship. Similarly, we can apply the bargained wage to eliminate $q^H(w)$ from (29) to obtain another balanced growth relationship in (n, g), which will be referred to as the *optimized human capital accumulation* (HA) relationship. Due to its complexity, we will defer any further discussion until the numerical section.

We are now prepared to characterize the effects of factor taxes on bargained wages, given $\{\mu, \eta, n, r\}$ and hence the effective capital-labor ratio q^F (refer to (18)). An increase in τ_K has a direct negative effect on the unit rental income (S_r), which decreases the household's marginal benefit and leads to a downward shift in the MB_w locus. On the contrary, there are two direct effects of higher labor taxation τ_L: one is to reduce S_w and thus shift the MB_w locus up and another is to suppress MB_w via the extensive margin of leisure. However, there are many indirect general equilibrium effects via the physical capital allocation share (s), work effort (ℓ) and the endogenous growth rate (g). The net effects of factor taxes on the MB_w locus are thus generally ambiguous. Since q^F is taken as given, it is clear that the MC_w locus will not respond to changes in factor tax rates. In the top panel of Figure 2, we depict the bargained outcomes based on the calibrated benchmark economy where both tax policies shift the MB_w locus downward, thereby decreasing the workers' option value and lowering their pre-tax wages. Due to a positive direct effect via S_w, it is not surprising that the resultant decrease in wages is smaller in response to an increase in labor compared to capital taxation. Such a difference is nonetheless smaller if the direct effect of labor taxation via leisure is stronger (e.g., when m is larger).

After solving the bargaining game, we then plot the wage discount-wage relationship (34) in the (w, Δ) space in the bottom panel of Figure 2 (where q^F and n are allowed to change). Notice

[9] The bargained wage rate and the equilibrium wage can be derived by solving the following quadratic equation:

$$S_w(1\text{-}\beta)F_1 w^2 + \{S_r q[(1\text{-}\beta)F_1 + \beta]\text{-}S_w F_2(1\text{-}\beta)\}w - S_r q[(1\text{-}\beta)F_2 + \beta(1\text{-}\alpha)Aq^{\alpha}] = 0$$

where $F_1 = \frac{(1-\tau_L)(1-\bar{b})+mn\ell S_w}{(1-\tau_L)(1-\bar{b})} > 0$ and $F_2 = \frac{-m(S_r qn\ell + T/h)}{(1-\tau_L)(1-\bar{b})} < 0$.

that this wage discount schedule only depends on the market effective capital-labor ratio q^F. By raising the pre-tax real rental rate and hence reducing q^F, an increase in τ_K shifts the wage discount schedule down; on the contrary, an increase in τ_L raises q^F and shifts the wage discount schedule up. In the case of labor taxation, it is expected that the bargained wage and the wage discount are negatively related as long as the direct effect dominates (which is the case in our calibrated economy). Thus, a higher labor tax is anticipated, leading to a lower wage discount. In the case of capital taxation, even if it has a negative effect on the bargained wage, its effect on the wage discount remains ambiguous. For illustrative purposes, the shifts depicted in the bottom panel of Figure 2 are based on the calibrated outcome (in which the wage discount is lower in response to a higher capital tax, but such a reduction is smaller than that in response to a higher labor tax in elasticities). We will thus relegate a complete characterization to the calibration section to which we now turn.

4 Numerical Analysis

We now turn to calibrating our benchmark model. We then conduct comparative-static exercises quantitatively, particularly focusing on the balanced growth effects of the two factor tax rates. We then perform tax incidence exercises and derive the optimal factor tax mix numerically. Finally, we perform sensitivity analysis to examine the robustness of our numerical results.

4.1 Calibration

We calibrate parameter values to match the U.S. quarterly data during the post-WWII period. We set the quarterly per capita real GDP growth rate to $g = 0.45\%$ and the quarterly depreciation rate of capital to 0.01 to match the annual per capita real GDP growth rate of 1.8% and the annual depreciation rate of capital in the range of $3 - 8\%$, respectively. With an annual time preference rate of 5%, we set our quarterly rate of time preference to 0.0125. The output elasticity of capital is set at the conventional value $\alpha = 0.36$. The capital rental rate can then be calibrated by using the observed capital-output ratio $k/y = 10.64$: $r = \frac{\alpha}{k/y} = 0.0338$. It is immediately known from (28) that $s = 0.999578$. Thus, in this calibrated economy, almost all of the physical capital inputs are used for goods production. As argued by Kendrick (1976), human capital is as large as physical capital. We thus set the physical to human capital ratio at $k/h = 1$.

Based on the observation and the factor tax incidence exercises conducted by Judd (1985) and many others, we set the pre-existing flat tax rates: $\tau_K = 0.2$ and $\tau_L = 0.2$. The ratio of unemployment compensation to the market wage ($\bar{b}$) is set to 0.42, in line with Shimer (2005) and Hall (2005). Also based on Shimer (2005), the monthly separation rate is given as 0.034 and the monthly job finding rate as 0.45. These enable us to compute the quarterly separation rate

$\psi = 1 - (1 - 0.034)^3 = 0.0986$ and the quarterly job finding rate $\mu = 1 - (1 - 0.45)^3 = 0.834$. From (22), we can compute: $n = \frac{\mu}{\mu+\psi} = 0.894$. By following Shimer (2005) to normalize the vacancy-searching worker ratio $(\frac{v}{u})$ as one, we can utilize (22) and (23) to calibrate $\eta = B = 0.834$ and use (25) to obtain $v = \frac{\psi n}{\eta} = 0.106$.

Next, we choose a reasonable value of equilibrium work effort $\ell = 0.725$ (i.e., 72.5% of household time is allocated to market work). Given the k/h ratio and the values of n, ℓ and s, the market and nonmarket effective capital-labor ratios are computed as: $q^F \equiv \dfrac{sk}{n\ell h} = 1.542$ and $q^H \equiv \dfrac{(1-s)\,k}{n\,(1-\ell)\,h} =$ 0.00172. The former can then be plugged into (18) to compute: $A = 0.124$. Since human capital investment is expected to be more human capital-intensive than goods production (i.e., $\gamma < \alpha =$ 0.36), we set $\gamma = 0.3$. We can then apply (29) and (30) to calibrate the two human capital accumulation scaling parameters: $D = 0.0179$ and $\widetilde{D} = 0.00290$. These can be substituted into (11) to obtain: $w = 0.00825$. This can further be plugged into (27) to yield $\phi = 4.1052$ and into (34) to compute $\Delta = 0.911$.

Moreover, we follow Andolfatto (1995), setting $\epsilon = 0.5$. In Andolfatto, the flow utility gain from leisure per employed is about twice as much as the comparable figure for the unemployed (the marginal valuation of leisure by the employed is higher). In addition, we conduct a quick accounting of the time use of the employed (40 hours work time per week for 50 weeks, the corresponding learning time consistent with our calibration, and the remaining time for leisure inclusive of a 2-week vacation), implying that the percentages of time for work, learning and leisure are 23%, 9% and 68%, respectively. We then calibrate m_1, m_2 and z to match the time allocation of the employed described above and to meet two additional targets based on Andolfatto: the ratio of the relative marginal utility of leisure of the employed to the unemployed (about 1.5) and the ratio of the level of the individual utility of leisure of the employed to the unemployed (about 2). This yields: $m_1 = 0.038$, $m_2 = 0.025$ and $z = 3.0$, which imply that $m = -m_2(1+z)^{-1} + m_1 z^{-1} = 0.064$ and $\beta = 0.1124$. Thus, by assuming bargaining to be efficient, our calibrated worker elasticity of matching is on the low side compared to the estimate obtained by Blanchard and Diamond (1990). Finally, we can compute $\frac{c}{h} = 0.0247$ and $\frac{T}{h} = 0.00754$ based on (31) and (21), respectively.

We summarize the observables, benchmark parameter values and calibrated values of key endogenous variables in Table 1.

4.2 Numerical Results

We next simulate the benchmark model to quantitatively examine the effects of two factor tax rates (τ_K and τ_L) on an array of endogenous variables of interest, including the balanced growth rate (g), effective consumption (c/h), the physical-human capital ratio (k/h), effective output (y/h), employment (n), work effort (ℓ), the wage (w), the wage discount (Δ), the workers' job finding rate (μ), the firms' employee recruitment rate (η), and firms' vacancies (v). The results obtained based on the responses of these endogenous variables around the balanced growth equilibrium to a 10% increase in each of the factor tax rates are reported in Table 2A.

In our calibrated economy, we can now quantify the effects of the two factor tax rates (τ_K and τ_L) on the bargained wage and the wage discount in our calibrated economy. A higher capital tax is found to lower the bargained wage and the wage discount slightly, whereas a higher labor tax reduces the wage rate but raises the wage discount. While capital taxation discourages vacancy creation and generates a negative effect on employment, labor taxation leads to opposite outcomes. Thus, the former lowers the worker's job finding rate but increases the firm's recruitment rate, while the latter generates opposite effects on these flow matching rates. Either tax suppresses learning effort and the balanced growth rate, as well as the after-tax capital rental rate and the after-tax effective wage rate. Since factor taxation has a stronger negative effect on the tax factor, the physical-human capital ratio falls in response to higher capital taxation, but rises in response to higher labor taxation. Our numerical results also suggest that a higher capital tax rate reduces output more than proportionately than human capital, but consumption less than proportionately, whereas labor taxation yields exactly the opposite results along the calibrated BGP.

To gain better insights, we plot in the (n, g) space the HA and FE loci based on the calibrated benchmark economy. As depicted in the top panel of Figure 3, both loci are upward-sloping. Intuitively, given the optimized human capital accumulation relationship, an increase in equilibrium employment enlarges the base of learners and hence promotes higher growth, implying an upward-sloping HA locus. The slope of the equilibrium firm efficiency relationship is in general ambiguous. Nonetheless, the direct effect of a higher level of equilibrium employment is to reduce the effective capital-labor ratio. By diminishing the marginal product, the marginal product of capital must rise, as will the capital rental rate. From the Keynes-Ramsey equation, a higher rate of balanced growth is implied. In the calibrated economy, our numerical results suggest that the direct effect dominates other indirect effects. We thus obtain an upward-sloping FE locus. Moreover, we can also see from (35) that as an increase in equilibrium employment lowers the effective capital-labor ratio, the household's marginal benefit decreases, whereas the firm's marginal cost increases. Thus, the equilibrium wage falls while the equilibrium wage discount rises. This positive relationship between employment and the wage discount is referred to as the wage bargain (WB) locus, and is depicted in the bottom panel of Figure 3.

We turn next to examining the growth effects of the factor taxes based on the calibrated benchmark economy, as depicted in the top panel of Figure 3. In response to an increase in the capital or labor tax rate, the HA locus shifts down. Since higher labor taxation encourages a shift from market to nonmarket activity, its effect on optimized human capital accumulation is not as large as that of capital taxation. Moreover, either tax increase reduces firm efficiency: for a given BGP market employment, the economic growth rate must be lower, implying a downward shift in the

FE locus. In equilibrium, our numerical results suggest that labor taxation induces a larger shift in human capital-based growth and hence the firm FE locus. This causes employment to rise and growth to decline in response to a higher labor tax. By contrast, in response to a higher capital tax, both employment and growth decline.

4.3 Factor Tax Incidence

We are now prepared to conduct tax incidence analysis in our endogenously growing economy. In particular, we change the composition of the two factor tax rates by keeping the government revenue unchanged. Under the pre-existing rates $(\tau_K, \tau_L) = (20\%, 20\%)$, the effective lump-sum tax is computed as $(T/h)^* = 0.00754$. This benchmark value will be kept constant and the government budget constraint (21) will remain balanced in our revenue-neutral tax-incidence exercises.

We next compute the social welfare measure along the BGP. Setting $h_0 = 1$, we can calculate the lifetime utility as follows:

$$\Omega = \frac{1+\rho}{\rho}\left[\ln(\frac{c}{h}) - m\,(1-n) + \frac{1}{\rho}\ln(1+g)\right] \tag{36}$$

where effective consumption is given by (31) with $T/h = (T/h)^*$. This is not a correct welfare measure, because there are flow profits that have accrued from bargaining in the presence of labor-market frictions. As discussed in the previous section, we can redistribute the flow profits to households to obtain a true welfare measure. From the definition of π and (16), the flow profit redistribution to each household in effective units is specified as:

$$\frac{\pi}{h} = n\ell\left[(1-\alpha)A\left(q^F\right)^{\alpha} - w\right] \tag{37}$$

Thus, the household's (redistribution) augmented effective consumption becomes:

$$\frac{c+\pi}{h} = \left[(1-\alpha)A\left(q^F\right)^{\alpha} + S_r q^F - (1-S_w)\,w\right]n\ell + (\frac{T}{h})^* \tag{38}$$

This value can be used to replace pre-redistribution effective consumption in (36) to compute augmented household value,

$$\Lambda\left(\frac{c+\pi}{h}, g\right) = \frac{1+\rho}{\rho}\left[\ln(\frac{c+\pi}{h}) - m\,(1-n) + \frac{1}{\rho}\ln(1+g)\right] \tag{39}$$

which is our social welfare measure. In short, social welfare is mainly driven by two endogenous variables: the economy-wide balanced growth rate and augmented effective consumption.

Figure 4 plots the dynamic factor tax incidence results. From Table 2, a higher capital tax than the pre-existing rate raises effective consumption, whereas a higher labor tax reduces it. Thus, the effect of a shift from labor to capital taxation on effective consumption turns out to be hump-shaped, peaking at around $\tau_K = 22\%$. A similar result holds for augmented effective consumption.

Both taxes generate detrimental growth effects. When the capital tax rate is within 5 percentage points of its pre-existing rate, a shift from labor to capital taxation reduces economic growth locally, although the magnitude of such effects is modest. Moreover, this growth effect is partly offset by the endogenous leisure effect. As a result, the lifetime utility of a household is hump-shaped, peaking around $\tau_K = 19.5\%$. By adjusting effective consumption and lifetime utility based on flow profit redistribution and combining these two effects (on augmented effective consumption and economic growth), the welfare measure is hump-shaped as well, peaking at a slightly lower capital tax rate of around $\tau_K = 19\%$. Specifically, the welfare measure is maximized at $(\tau_K^*, \tau_L^*) = (19.07\%, 24.56\%)$. That is, in the absence of other tax alternatives, the socially optimal factor tax mix requires a mild decrease in the capital tax rate in conjunction with a modest increase in the labor tax rate from their benchmark values. Such a tax reform will lead to a 0.18% increase in economic growth and a small 0.0044% increase in welfare (0.013% in consumption equivalence), because the optimal tax mix is not too far from the pre-existing figure. Our finding that the optimal capital tax rate is *significantly larger than zero* is in sharp contrast to the dynamic factor tax incidence literature within both the exogenous and endogenous growth frameworks.

It is important to understand the numerically dominant channel underlying this shocking finding: the *vacancy creation-labor participation* channel. Specifically, under an efficiency wage bargain, if the capital tax rate is initially too low, then a higher tax on capital income accompanied by a revenue-neutral reduction in the labor tax turns out to raise the wage discount and to encourage firms to create more vacancies. This in turn raises the job finding rate and hence induces workers to more actively participate in the labor market to seek employment. Because this leads to positive effects on employment and output growth, a shift from a zero to a positive capital tax rate becomes welfare-improving, thereby yielding a policy recommendation different from that of Chamley-Judd-Lucas.[10]

4.4 Sensitivity Analysis

While our pre-set parameters in the calibration exercises are all basically justified, some of the calibration criteria may be argued to be open to discussion. We therefore perform sensitivity analysis to check the robustness of our results. In particular, we consider the following alternatives:

(i) We allow the labor-market tightness, $\theta = v/(1-n)$, to fall in a wide range $[0.5, 2]$.

(ii) We allow the leisure preference parameter, m, to be 50% below and above its benchmark value.

[10] It should be noted that the wage discount effect is dominant, leading to a strong vacancy creation-labor participation effect around $\tau_K = 0$, but is not strong enough around the pre-existing tax rates. That is, the optimal tax mix still features an optimal capital tax lower than the pre-existing rate of 20%.

(iii) We allow the ratio of the unemployment compensation to the market wage, $\bar{b}$, to be 5 percentage points below and above its benchmark value.

(iv) We allow the capital share of human capital accumulation, γ, to be 5% below and above its benchmark value.

(v) We allow the amount of physical capital to be half or twice as large as the amount of human capital, i.e., $k/h = 0.5, 2$.

The sensitivity analysis results are reported in Table 3.

When we recalibrate the model with different labor-market tightness measures, different capital shares of human capital accumulation, or different physical-human capital ratios, labor-market matching, bargaining and human capital accumulation are either unchanged or changed only negligibly. Thus, the wage discount effect and the vacancy creation-labor participation channel are essentially identical to those in the benchmark case, thereby leaving the factor tax incidence result largely unaffected.

When the leisure preference parameter is 50% above its benchmark value, the direct effect of labor taxation on leisure is so strong that the detrimental effect of a higher labor tax on the marginal benefit of the household in a wage bargain is larger than that of a higher capital tax. Due to its greater distortion on the wage discount, labor taxation is more harmful to welfare. The optimal tax mix in this case turns out to feature a shift from labor to capital taxation: $(\tau_K^*, \tau_L^*) = (20.46\%, 17.76\%)$. On the contrary, when the leisure preference parameter is 50% below its benchmark value, the optimal tax mix becomes: $(\tau_K^*, \tau_L^*) = (16.80\%, 35.62\%)$, which still features a large positive tax on capital income.

When the unemployment compensation-market wage ratio is 5 percentage points higher (i.e., $\bar{b} = 0.42 + 0.05$), it is required that the government raise both tax rates in order to maintain a balanced budget. Relatively speaking, however, the overall distortion of τ_L increases as a result of the reduced incentive for working or accumulating human capital. Therefore, the optimal tax mix becomes: $(\tau_K^*, \tau_L^*) = (20.78\%, 13.56\%)$, which features a shift from labor to capital taxation. Conversely, when the unemployment compensation-market wage ratio is 5 percentage points lower ($\bar{b} = 0.42 - 0.05$), the optimal tax mix features a complete elimination of the capital tax: $(\tau_K^*, \tau_L^*) = (0\%, 37.68\%)$. That is, when the household's incentive for working or accumulating human capital is sufficiently strong, the overall distortion of labor taxation becomes insignificant. It is therefore welfare-improving to fully replace the more distortionary capital tax by the labor tax.

5 Alternative Setups

In this section, we consider three alternative setups, labeled as Models I-III, that may potentially favor a higher tax imposed on labor income. The first two are on the household side while keeping the firm's optimization problem unchanged, whereas the last is a Walrasian model where there is no labor market friction. Table 4 summarizes the main tax incidence results.

5.1 Model I: Inelastic Leisure

In the benchmark model with endogenous labor-leisure choice, labor-related decisions become more elastic, implying that the tax on labor income is more distortionary than the case with inelastic leisure. While this *labor participation response* is tied to the extensive margin of leisure, just how important such a channel is to the optimal tax mix outcome is a quantitative matter.

With inelastic leisure, we take $m = 0$ and recalibrate $\beta = 0.0823$. By performing tax incidence analysis (see the results reported in Row 1, Table 4), we find that the optimal tax mix (τ_K^*, τ_L^*) is now at $(9.15\%, 68.79\%)$, featuring a sizable shift from capital to labor taxation. This suggests that with inelastic leisure, taxing labor becomes quantitatively much less harmful. In this case, a tax reform will lead to a nonnegligible welfare gain of 0.60% (in consumption equivalence).

5.2 Model II: Linear Human Capital Accumulation Function

In the benchmark case, we assume that human capital and physical capital are both required for human capital accumulation. Now we consider an alternative setup of human capital formation where only human capital is used as an input (the Lucasian human capital formation). One can think of this as a special case of (2) with $\widetilde{D} = 0$ and $s = 1$. That is,

$$h_{t+1} - h_t = Dn_t(1 - \ell_t)h_t$$

The modified optimization and BGP conditions are presented in the Appendix. Recall that human capital production is tax-exempt. When market goods (physical capital) are no longer inputs to human capital accumulation, the entirety of physical capital must be subject to taxation. As a consequence, the overall distortion of τ_K rises and the optimal tax mix now features a larger shift from capital to labor taxation: $(\tau_K^*, \tau_L^*) = (17.87\%, 30.70\%)$, which generates a larger welfare gain of 0.072% (in consumption equivalence), compared to the benchmark case. Our results imply that optimal taxation is not too sensitive to the form of human capital accumulation.

5.3 Model III: Walrasian Economy

To highlight the role played by labor-market frictions, we investigate the tax incidence outcome in a frictionless Walrasian economy with full employment. By construction, $n = 1$ and hence there is no extensive margin of leisure. The modified optimization and BGP conditions are presented in the Appendix. By comparing it with the optimal tax mix result in our benchmark case, the role of labor-market frictions can be identified. Specifically, we find that the optimal tax mix becomes: $(\tau_K^*, \tau_L^*) = (0\%, 27.51\%)$, which restores the Lucasian policy recommendation – the optimal tax mix in the Lucas (1990) case is $(\tau_K^*, \tau_L^*) = (0\%, 46\%)$ based on higher pre-existing tax rates $(\tau_K, \tau_L) = (40\%, 36\%)$. Thus, even in a human capital-based endogenous growth model, one should replace capital taxation fully by labor taxation *if the labor market is frictionless*. This verifies our intuition: it is the labor-market frictions that lead to a different dynamic factor tax incidence conclusion from previous studies.

6 Concluding Remarks

In this paper, we have developed a human capital-based endogenous growth framework with labor market search and entry frictions that permit individuals to participate in the labor force voluntarily. By conducting dynamic factor tax incidence exercises, we have found that it is never optimal to set the capital tax rate to zero when both physical and human capital are used as inputs of human capital accumulation. We have shown that, in the benchmark case with physical capital entering the human capital accumulation process and with a pre-existing flat rate of 20% on both capital and labor income, a partial shift from capital to labor taxation maximizes social welfare – this main finding is robust to different parameterization as well as to alternative setups with inelastic leisure or with a Lucasian human capital accumulation process that is independent of market goods (physical capital). Our results suggest that, in order to enhance social welfare, a proper tax reform must take into account labor market frictions. When such frictions are substantial, fully replacing capital with labor income taxation can be welfare-retarding.

For future research along these lines, it is perhaps most interesting to incorporate a pecuniary vacancy creation cost that requires capital financing. In the presence of credit market frictions as a result of private information, such a financing constraint is anticipated to increase the capital tax distortion. On the contrary, one may also extend the model to allow the separation rate to depend on on-the-job learning effort (as in Mortensen 1988). Since the labor income tax discourages on-the-job learning, it is anticipated that such a generalization may cause the labor tax to be more distortionary. Thus, both extensions call for a revisit of dynamic factor tax incidence exercises: while the former may favor a shift from taxing capital to taxing labor income, the latter may yield opposite policy outcomes.

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Appendix

(Not Intended for Publication)

In the Appendix, we provide mathematical details of the Alternative Models II (linear human capital accumulation) and III (Walrasian).

Alternative Model II: Linear Human Capital Accumulation

In the case with a linear human capital accumulation process independent of market goods, the first-order condition of the household's optimization problem (5) is the same while (6) becomes:

$$\Omega_k(\mathcal{H}')(1-\tau_L)w = \Omega_h(\mathcal{H}')D \tag{A1}$$

The Benveniste-Scheinkman conditions of the household's optimization problem are now:

$$\Omega_k(\mathcal{H}) = \frac{1}{1+\rho}\Omega_k(\mathcal{H}')[(1-\delta_k)+(1-\tau_K)r] \tag{A2}$$

$$\Omega_h(\mathcal{H}) = \frac{1}{1+\rho}\left\{\Omega_k(\mathcal{H}')(1-\tau_L)w[n\ell+(1-n)\bar{b}]+\Omega_h(\mathcal{H}')[1+Dn(1-\ell)]\right\} \tag{A3}$$

$$\Omega_n(\mathcal{H}) = m + \frac{1}{1+\rho}\left[\Omega_k(\mathcal{H}')\left(\ell-\bar{b}\right)(1-\tau_L)wh+\Omega_h(\mathcal{H}')D(1-\ell)h+\Omega_n(\mathcal{H}')(1-\psi-\mu)\right] \tag{A4}$$

The BGP equilibrium expressions follow by simply setting $\widetilde{D}=0$ and $s=1$.

Alternative Model III: Walrasian Model

We consider a Walrasian economy with $n=1$. Let $q_t^H = \dfrac{(1-s_t)k_t}{(1-\ell_t)h_t}$ and $q_t^F = \dfrac{s_t k_t}{\ell_t h_t}$. Then the firm's optimal decisions are:

$$\alpha A\left(q_t^F\right)^{\alpha-1} = r_t \tag{A5}$$

$$(1-\alpha)A\left(q_t^F\right)^{\alpha} = w_t \tag{A6}$$

Combining (A5) and (A6), we have:

$$q_t^F = \frac{\alpha w_t}{(1-\alpha)r_t} \tag{A7}$$

The household faces the following budget constraint:

$$k_{t+1} = (1-\tau_L)w_t\ell_t h_t + [(1-\delta_k+(1-\tau_K)r_t]k_t - c_t + T_t \tag{A8}$$

The main change is the Benveniste-Scheinkman condition with respect to h:

$$\Omega_h(\mathcal{H}) = \frac{1}{1+\rho}\left\{\Omega_k(\mathcal{H}')(1\text{-}\tau_L)w\ell+\Omega_h(\mathcal{H}')\left[1+(1\text{-}\ell)\left[D+\widetilde{D}(1\text{-}\gamma)\left(q^H\right)^{\gamma}\right]\right]\right\} \tag{A9}$$

By imposing a log utility function $U(c)=\ln c$, we can derive the following equations along the BGP:

$$\rho+(1+\rho)g = \left[D+\widetilde{D}(1-\gamma)\left(q^H\right)^{\gamma}\right] \tag{A10}$$

$$\ell = 1-\frac{g}{D+\widetilde{D}\left(q^H\right)^{\gamma}} \tag{A11}$$

The generalized Keynes-Ramsey relationship (28) and (11) remain unchanged. The effective consumption along a BGP is:

$$\frac{c}{h} = (1-\tau_L)w\ell + \left[(1-\tau_K)r - \frac{g+\delta_k}{s}\right]q^F\ell + \frac{T}{h} \tag{A12}$$

Table 1: Benchmark Parameter Values and Calibration

Benchmark Parameters and Observables		
per capita real economic growth rate	g	0.0045
physical capital's depreciation rate	δ_k	0.0100
time preference rate	ρ	0.0125
tax rate on capital	τ_K	0.2000
tax rate on income	τ_L	0.2000
unemployment insurance	$\bar{b}$	0.4200
capital's share	α	0.3600
capital-output ratio	k/y	10.6400
physical capital-human capital ratio	k/h	1.0000
fraction of time devoted to work	l	0.7250
job separating rate	ψ	0.0986
job finding rate	μ	0.8336
vacancy-searching worker ratio	v/u	1.0000
parameter of human capital accumulation	γ	0.3000
preference parameter of leisure	ε	0.5000
Calibration		
coefficient of goods technology	A	0.1240
coefficient of matching technology	B	0.8336
consumption-human capital ratio	c/h	0.0247
transfer-human capital ratio	T/h	0.0075
fraction of physical capital devoted to goods production	s	0.9996
effective capital-labor ratio in the nonmarket sector	q^H	0.0017
effective capital-labor ratio in the market sector	q^F	1.5418
coefficient of the cost of vacancy creation and management	ϕ	4.1052
coefficient of human capital accumulation	D	0.0179
coefficient of human capital accumulation	$\widetilde{D}$	0.0029
rate of return of capital	r	0.0338
fraction of time devoted to employment	n	0.8943
preference parameter of leisure	m	0.0640
labor searcher's share in matching production	β	0.1124
vacancy creation	v	0.1057
employee recruitment rate	η	0.8336
wage	w	0.0082
wage discount	Δ	0.9111

Table 2: Numerical Results (τ_K=20%, τ_L=20%)

	Benchmark	τ_K increases	τ_L increases
g	**0.004500**	-0.065257	-0.004813
c/h	**0.024667**	0.005524	-0.001997
k/h	**1.000000**	-0.403199	0.003816
y/h	**0.093945**	-0.156321	0.003006
s	**0.999578**	-0.000085	0.000169
n	**0.894259**	-0.030281	0.001221
$1-n$	**0.105741**	0.254314	-0.010330
l	**0.725000**	0.012883	0.001234
$(1-l)n$	**0.245921**	-0.064285	-0.002032
q^H	**0.001715**	-0.139229	-0.399016
q^F	**1.541755**	-0.385887	0.001531
r	**0.033835**	0.246972	-0.000980
$(1-\tau_K)r$	**0.027068**	-0.010890	-0.000980
w	**0.008247**	-0.109036	-0.024395
$(1-\tau_L)w$	**0.006597**	-0.109036	-0.282256
Δ	**0.911074**	-0.002920	0.002433
μ	**0.833625**	-0.284594	0.011551
η	**0.833625**	0.036033	-0.001462
ν	**0.105741**	-0.066314	0.002684

Note: Numbers reported in columns 2~3 are elasticities of key variables with respect to each exogenous shift in tax rates.

Table 3: Sensitivity Analysis

	τ_K^*	τ_L^*	$(g^*-g)/g$	$(\Lambda^*-\Lambda)/\Lambda$	Welfare gain in consumption equivalence
Benchmark	**19.07**	**24.56**	**0.1839**	**0.0044**	**0.0128**
$\theta = 0.5$	19.07	24.56	0.1839	0.0044	0.0128
$\theta = 2$	19.07	24.56	0.1839	0.0044	0.0128
m = 0.064*0.5 (0.0512)	16.80	35.62	0.5491	0.0414	0.1201
m = 0.064*1.5 (0.0768)	20.46	17.76	-0.0951	0.0012	0.0035
$\bar{b} = 0.37$	0.00	37.68	0.4020	1.8501	4.8201
$\bar{b} = 0.47$	20.78	13.56	0.0384	0.0056	0.0164
γ = 0.3*0.95 (0.285)	19.07	24.56	0.1812	0.0044	0.0127
γ = 0.3*1.05 (0.315)	19.07	24.56	0.1864	0.0044	0.0128
$k/h = 0.5$	19.07	24.56	0.1839	0.0036	0.0128
$k/h = 2$	19.07	24.56	0.1839	0.0058	0.0128

Note: Numbers reported are in percentage.

Table 4: Tax Incidence Analysis under Various Setups

	τ_K^*	τ_L^*	$(g^*-g)/g$	$(\Lambda^*-\Lambda)/\Lambda$	Welfare gain in consumption equivalence
Benchmark	**19.07**	**24.56**	**0.1839**	**0.0044**	**0.0128**
I. Inelastic leisure	9.15	68.79	0.7757	0.2064	0.5991
II. Linear HCA	17.87	30.70	0.5995	0.0249	0.0724
III. Walrasian	0.00	27.51	5.4285	4.5347	10.3581

Note: Numbers reported are in percentage.

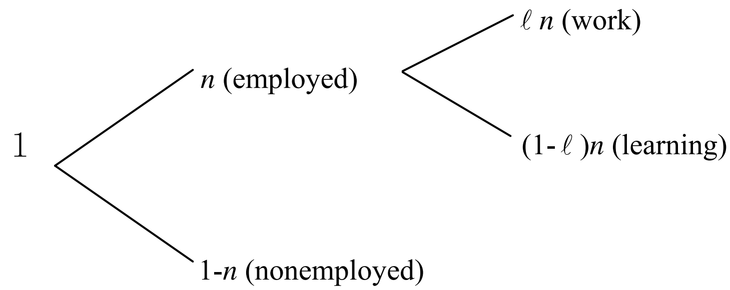
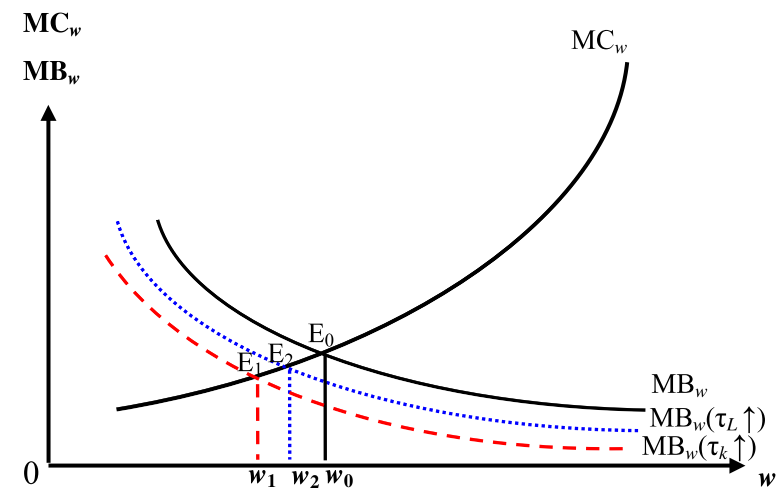


Figure 1: Labor Allocation of the Day Time



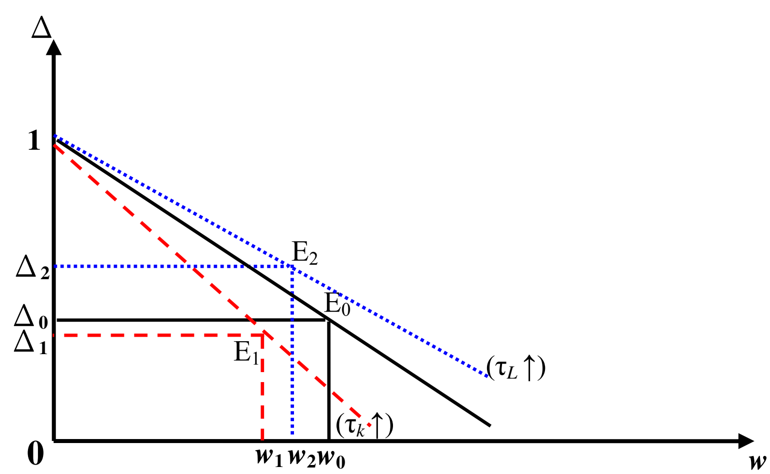
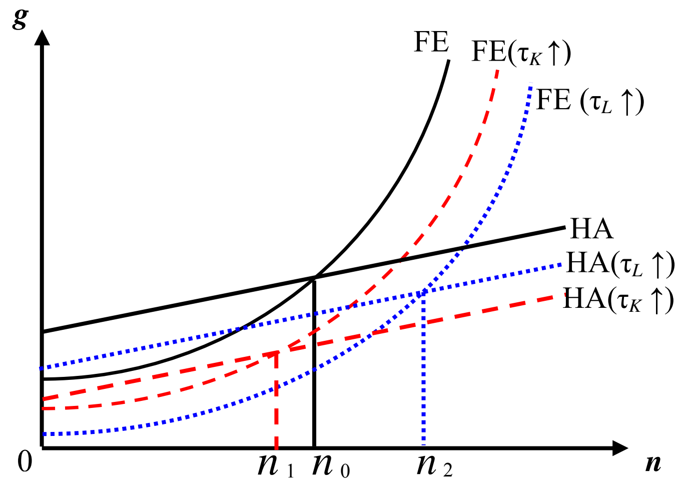


Figure 2: Effects of Factor Taxes on Wage Bargaining: Higher τ_K or τ_L



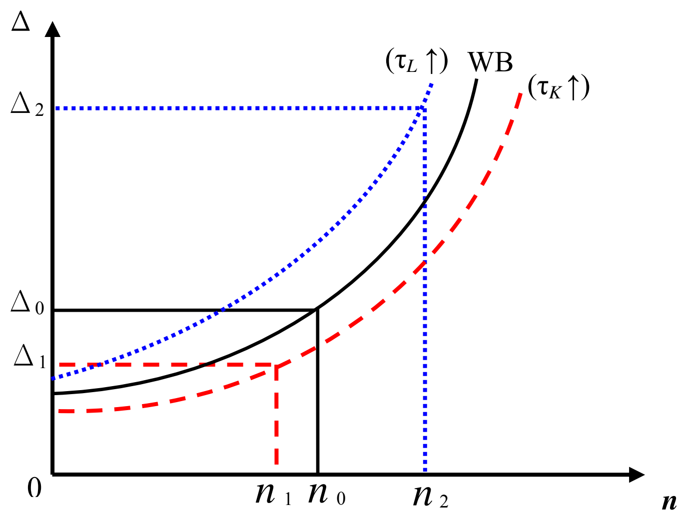


Figure 3: Growth Effects of Factor Taxes

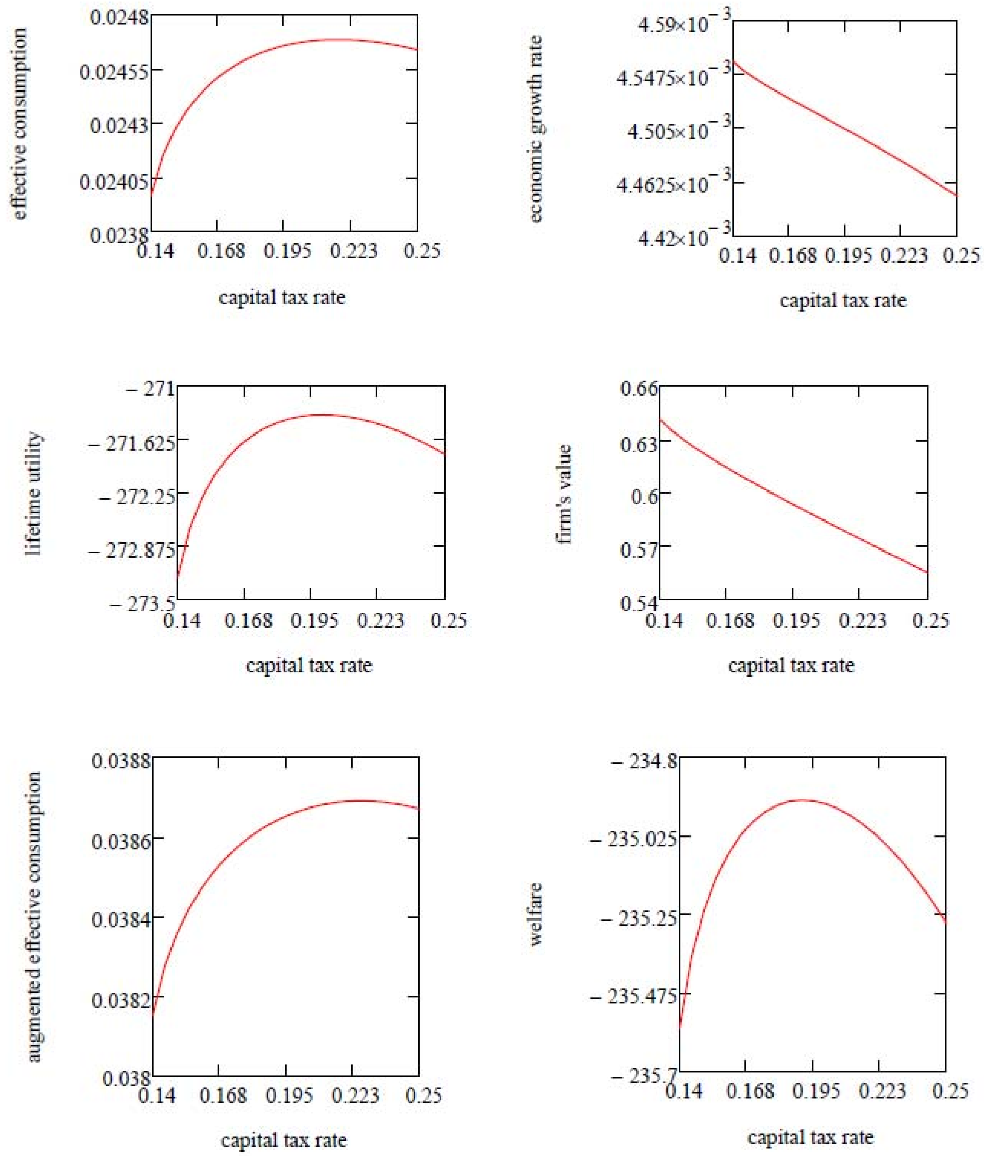


Figure 4: Dynamic Tax Incidence Results