SUPPLY SIDE INTERVENTIONS AND REDISTRIBUTION[*]

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Abstract

In this paper we study the welfare impact of alternative tax schemes on labor and capital. We evaluate the effect of lowering capital income taxes on the distribution of wealth in a model with heterogeneous agents, restricting our attention to policies with constant tax rates.
We calibrate and simulate the economy; we find that lowering capital taxes has two effects: i) it increases efficiency in terms of aggregate production, and ii) it redistributes wealth in favor of those agents with a low wage/wealth ratio. We find that the redistributive effect dominates, and that agents with a high wage/wealth ratio would experience a large loss in utility if capital income taxes were eliminated.

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1 Introduction

The study of distortionary taxation in neoclassical growth models with rational expectations has received considerable attention in the last fifteen years. These models integrate the study of public finance and macroeconomic issues in a consistent framework; they generate predictions about the effect of taxes on the dynamics of the economy, the model can be tested with time series data, changes in policy can be analyzed without falling prey to the Lucas critique, and the benefits of a given policy can be analyzed with measures of agents' utilities.

A large part of the literature has reached the conclusion that capital taxes should be abolished or, at the very least, severely reduced; the decrease in revenues should be compensated by a higher labor tax. Then aggregate investment and production would grow and, in the long run, consumption would also be larger. The study of taxation in rational expectations models has provided rigorous ground for an old idea in economics: a decrease in capital taxes would increase the size of the pie.

This conclusion agrees with the recommendations of the so-called Supply-side economics and with the economic policy prevalent in the 80's; for example, according to the average effective marginal tax rates reported by McGrattan, Rogerson and Wright [1997]

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for the US, capital taxes were on average .5 from 1981-87, down from an average of .6 in the period 1947-80, while labor taxes were .27, up from .22, during the same periods.

Unfortunately, most of the literature uses homogeneous agent models, and it ignores redistributive effects.[1] Abolishing capital taxes would also imply a redistribution of wealth against those agents with a lower proportion of capital income over labor income; these agents may or may not be better off depending on whether the aggregate efficiency effect dominates the redistributive effect. This is precisely the issue studied in this paper. The answer to this question is not obvious because it may be impossible to guarantee that all agents gain from this reform, since lump-sum redistribution is not available.[2]

Our model has n types of agents differing in the level of wealth. In order to make our results comparable to the existing literature, everything in the model is as close as possible to the standard neoclassical paradigm: we assume time-separable utilities, exogenous growth, endogenous production, complete markets for loans, competitive markets for all goods, full information, productivity shocks, rational expectations, etc.. We reproduce the usual result that a reduction in capital taxes enhances economic activity: wages, aggregate investment, aggregate consumption and aggregate output all increase by a significant amount. Nevertheless, we find that abolishing capital taxes also changes the distribution of wealth in a major way; the redistributive effect is so important that the utility of agents with a high wage/wealth ratio decreases dramatically; only consumers with a low wage/wealth are better off. The effects on welfare are very large. In the model with five types of agents, by abolishing capital taxes the welfare of 20% of the population would be reduced dramatically, and a large part of the population is likely to loose.[3]

We choose most parameter values in order to match some basic observations from aggregate time series data, as is usually done in real business cycle studies. The parameters that determine the relative wealth of individuals are chosen by splitting observations on households in the PSID data set in five equally sized groups; the criterion for splitting the sample is such that, within our model, agents in the same group would be affected in a similar way by the change in economic policy that we are considering. The elasticity of leisure is chosen so as to match variability across agents of hours worked. This issues are discussed in a stochastic model for two reasons: first, we can show that our model with taxes matches the observed correlations and volatilities that standard real business cycle literature has focussed on. Second, we can point out a puzzle that standard real business cycle models face when heterogeneity is introduced: volatility of hours worked is higher than volatility of consumption across time, but the reverse inequality occurs across individuals.

The model is analyzed by simulation techniques[4], since analytic results are not available. Finding a numerical solution is complicated by three features of the model: i) no planner problem supports the equilibrium, ii) non-linearities are important since, after the change in policy, the initial condition is far from the steady state, and iii) the share of output that each agent consumes is endogenous to the tax system. Difficulties i) and iii) have usually been solved in the literature by introducing lump-sum taxes back in the model, but we avoid this alternative, since it would mask the redistributive effects of a pure change in distortionary taxes.

The plan of the paper is as follows: the literature is reviewed in section 2. The model is presented in section 3. Section 4 discusses some analytic results for special cases. Section 5 discusses issues of calibration of the parameters using data from the US economy. Section 6 presents the results derived from the simulations. The conclusion ends the main paper. The appendices discuss the introduction of uncertainty, computational issues as well as the conversion of the model with growth to one in terms of deviations from growth, and details on the calibration of heterogeneity parameters from the PSID data set.

2 Review of the Literature

The progress in the study of taxation in dynamic equilibrium models has been notorious in the last ten years. In his seminal contribution, Chamley [1986] showed that the optimal policy should tax the capital already in place in the first few periods, and eliminate all distortions on investment decisions by suppressing capital taxes in the long run. In other words, the optimum tax satisfies $\tau_t^k \to 0$ as $t \to \infty$). This conclusion is robust to many different environments. Subsequent papers have qualified this conclusion: Chari, Christiano and Kehoe [1994], Zhu [1992] and Aiyagari [1993] in models with uncertainty[5] and Jones, Manuelli and Rossi [1993], Milesi-Ferretti and Roubini [1998] in models with human capital[6].

The optimal policy calls for raising enormous tax rates on capital in the first few periods, and a decrease of tax rates only after the government has very high savings. In the long run, government would finance its expenditures by interest income and, perhaps, other taxes. Unfortunately, actual governments would find it difficult to implement this policy for two reasons: private agents should be able to accumulate huge amounts of debt in the first few periods, so that consumers' liquidity constraints are likely to be binding; also, governments might find it difficult to make the optimal policy credible due to its extreme time-inconsistency.[7] This motivated some authors to study policies with constant tax rates; for example, Lucas [1990] studied the benefits of establishing the long-run optimum from period zero (i.e., setting $\tau_t^k = 0$ for $t = 0; 1; \ldots$); he found that the gains in welfare would be significant. Cooley and Hansen [1992] show that the qualitative conclusions of Lucas are robust even if other types of taxes are introduced and if the transition to the new steady is properly incorporated. Chari, Christiano and Kehoe [1994] in their 'Constant Policy Experiments' show that the result is robust to introducing uncertainty, and variations in certain parameter values; they find that the welfare gain would be small and, for some parameter values, it may be slightly negative; they also argue that the behavior of taxes along the transition path is what drives most of the gain in welfare of the optimal policy.

Most of the above work assumes homogeneous consumers. Several papers on optimal taxation have introduced heterogeneity, including Chamley [1986], Judd [1987] and Zhu [1992], often to find that results are not affected by heterogeneity. In particular, they show that the optimal tax on capital is zero (or near zero) in the long run even with heterogeneous consumers. The point of our paper can be interpreted as saying that, with heterogeneous agents, the transitional path of the optimal policy is crucial in reaching allocations where both agents improve; this is because, in the absence of agent-specific taxes, the budget constraint of the agents acts as a binding constraint that slows down reaching the long-run optimum of $\tau^k = 0$. We will show that, if the optimum is implemented from period zero, since there is only one implied weight (or, more precisely, only one share of output for each agent) that is consistent with a given tax rate, half of the population may suffer a large welfare loss.

A few papers have introduced heterogeneity in models of non-optimal taxation. Judd [1985] studies the effect of small changes in the capital tax rate under some simplifying assumptions, for particular parameter values and in a continuous time model; he finds cases where a small decrease in capital taxes would benefit all agents, while in other cases a small decrease would hurt the less wealthy agents; our purpose is to study the effect of a large change in taxes in a model where parameters are calibrated from the data, so that Judd's results are helpful to build intuition, but they are inconclusive given our purpose. Also, Krusell and Ríos-Rull [1994] show that, in a model where agents vote in every period, a reduction in taxes would never be approved democratically; they interpret their result as implying that a reduction in taxes should be voted at time 0 and then written in the constitution; our result in section 5 argues that abolishing capital taxes may not be voted, even if it were written in the constitution.[8]

3 The Model

In this section we describe a simple neoclassical growth model with heterogeneous agents, endogenous production, labor choice, uncertainty, exogenous growth[9], and government spending that is financed exclusively with distortionary taxes. We think of each agent as representing wealth groups of equal size; in order to match observations, the n types of agents will be allowed to differ both in terms of their human, and non-human wealth.

3.1 Consumer, Firm, and Government Behavior

n infinitely-lived consumer types indexed by $j = 1, 2, \ldots, n$ derive utility from consumption and leisure, are endowed with one unit of time every period and a certain amount of capital stock in the initial period. The number of each type of agents is normalized to $1/n$. They receive income from working and from renting their capital. Agents can borrow, lend, and insure one another through a full range of one-period contingent claims. Their labor and capital incomes are taxed at constant rates τ^l and τ^k. Uncertainty is driven by a stochastic shock to productivity θ_t Markov of order one with finite non-negative support. Throughout the paper, index t is assigned to random variables known with information available at time t, and θ indexes all possible values of the shock.

Consumers of type j solve the following maximization problem:

$$\max_{\{x_{jt}\}} \quad E_0 \sum_{t=0}^{\infty} \delta^t \left(u(c_{j,t}) + v(l_{j,t}, \mu^t) \right)$$

subject to

$$\begin{aligned} c_{j,t} + k_{j,t} - k_{j,t-1} + \textstyle\int q_t(\theta)\, m_{j,t}(\theta) d\theta \;=\; & \\ \phi_j \, \mu^t \, l_{j,t} \, w_t (1 - \tau^l) + \; & k_{j,t-1}(r_t - d)(1 - \tau^k) + m_{j,t-1}(\theta) \end{aligned} \qquad (1)$$

$$\begin{aligned} k_{j,t} &= (1 - d) k_{j,t-1} + i_{j,t} \\ k_{j,-1} \text{ and } m_{j,-1}(\theta) & \quad \text{given} \end{aligned}$$

where the consumer chooses over $\{x_{j,t}\} \equiv \{c_{j,t}, l_{j,t}, \{m_{j,t}(\theta)\}_\theta, i_{j,t}, k_{j,t}\}_{t=0}^{\infty}$. We assume separability in time and in the consumption-leisure decision. Since we concentrate our study on issues of distribution, agents only differ in initial wealth and the efficiency of labor.

Here, $c_{j,t}, i_{j,t}, k_{j,t}, m_{j,t}, l_{j,t}$ denote consumption, investment, capital stock, demand for contingent claims and hours worked of agent j at time t; q_t, w_t, r_t denote prices of contingent claims, efficiency units of work, and capital rental, normalized in terms of the consumption good of the period. Variables without a subindex j represent economy-wide variables (i.e., prices or aggregate allocations). Parameters δ and d are in the interval [0,1] and they represent the discount factor of future utility and the depreciation rate of capital. Taxes on labor and capital are given by τ^l and τ^k; taxes on capital are after depreciation allowances. Functions u and v are differentiable and satisfy the appropriate Inada conditions; furthermore, $u(\cdot)$ and $v(\cdot, \mu)$ are strictly concave; $u(\cdot)$ and $v(l, \cdot)$ are strictly increasing and $v(\cdot, \mu)$ is strictly decreasing. Each consumer chooses a portfolio of contingent claims $\{m_{j,t}(\theta); \forall\theta \in R\}$; where $m_{j,t}(\theta)$ represents the demand of claims that pay one unit of consumption in $t+1$ contingent on $\theta_{t+1} = \theta$ being realized. The payoff of the portfolio bought last period is given by $m_{j,t-1}(\theta_t)$.[10].

Growth will be introduced through exogenous accumulation of human capital in the production function at a rate $\mu \geq 1$. This is the simplest alternative that avoids degenerate solutions for hours worked in the long-run. In section 4 we are more precise about a functional form for u and v that maintains interior solutions along the growth path; most of the simulations we report are for $u(c) = \log(c)$, in which case μ^t drops out from the utility function altogether. The efficiency of each agent's labor is indexed by parameters $\phi_j > 0$; these are normalized so that $\sum_{j=1}^{n} \phi_j = 1$. Notice that we assume that all agents are allowed to hold capital. This completes the description of the consumer side of the economy.

There is one representative firm that maximizes period-by-period profits; it manages a production technology, rents capital at a price r_t and hires efficiency units of labor at a wage w_t to solve

$$\max_{(y_t, e_t, k_{t-1})} y_t - w_t e_t - r_t k_{t-1} \tag{2}$$

$$\text{s.t.} \quad y_t = F(k_{t-1}, e_t, \theta_t) \tag{3}$$

$$\frac{1}{n}\left(\sum_{j=1}^{n} \phi_j l_{j,t}\right) \mu^t = e_t \tag{4}$$

where y_t represents output, k_t the demand of capital, and e_t the demand for efficiency units of labor. The stochastic shock $\{\theta_t\}$ has been described above. F is the production function gross of depreciation, strictly concave and homogeneous of degree one with respect to (k_{t-1}, e_t): Equation (4) represents efficiency units in terms of hours worked by each agent; notice that the number of each type of agents is normalized to $1/n$; this, and the assumption that the ϕ's add up to one guarantees that setting $\phi_i = \phi_j$, $m_{i,-1} = m_{j,-1}$ and $k_{i,-1} = k_{j,-1}$ for $i, j = 1, 2, \ldots, n$ we are back to a version of the homogeneous agent model used by Lucas, Cooley and Hansen, and Chari, Christiano and Kehoe.

Government spending grows at a constant rate starting at a level g; so the sequence of government consumption is given by $g_t \equiv \mu^t g$ [11]. Government can accumulate debt by selling contingent claims, and its period-t budget constraint is given by

$$g_t = (r_t - d)\, k_{t-1}\tau^k + w_t\, e_t \tau^l - \int q_t(\theta)\, m_{g,t}(\theta) d\theta + m_{g,t-1}(\theta_t) \tag{5}$$

Agents are assumed to observe all variables realized at time t, so that their decisions at time t are measurable with respect to $(\theta_0, \theta_1, \ldots, \theta_t)$; the time-invariant probabilities are known to all agents.

3.2 Definition and Characterization of Equilibrium

We assume competitive equilibrium. An equilibrium is defined as a stochastic process for prices and allocations, and a government policy for (g, τ^k, τ^l) such that: when consumers maximize utility and firms maximize profits taking prices and government policy as given, they choose allocations such that all markets clear, and the budget constraint of the government is satisfied. Market clearing in consumption good, capital, and contingent claims is given by

$$\frac{1}{n}\sum_{j=1}^{n} c_{j,t} + g_t + k_t - (1-d)k_{t-1} = y_t \tag{6}$$

$$\frac{1}{n}\sum_{j=1}^{n} k_{j,t} = k_t \tag{7}$$

$$\frac{1}{n}\sum_{j=1}^{n} \left(m_{j,t}(\theta) + m_{g,t}(\theta)\right) = 0 \tag{8}$$

for all θ and for all t, and clearing in the labor market is given by (4).

With interior solutions, the first order conditions for contingent claims, capital, and labor choice in the consumer's problem are as follows:

$$q_t(\theta)\, u'(c_{j,t}) = \delta\, u'(c_{j,t+1}(\theta))P(\theta = \theta_{t+1} \mid \theta_t) \tag{9}$$

$$u'(c_{j,t}) = \delta\, E_t \left[u'(c_{j,t+1}) \left((r_{t+1} - d)(1-\tau^k) + 1 \right)\right] \tag{10}$$

$$u'(c_{j,t})\, w_t\, (1-\tau^l)\, \mu^t \phi_j + v'(l_{j,t};\mu^t) = 0 \tag{11}$$

for all t and $j = 1, 2, \ldots, n$. Here, $v' \equiv \frac{\partial v}{\partial l}$. In equation 9, $c_{j,t+1}(\cdot)$ denotes explicitly equilibrium consumption of agent j in period $t+1$ as a function of the realization $\theta = \theta_{t+1}$; $P(\cdot \mid \cdot)$ denotes the conditional probability.[12] As usual, equilibrium factor prices equal marginal product to set $r_t = F_1(k_{t-1}, e_t, \theta_t)$ and $w_t = F_2(k_{t-1}, e_t, \theta_t)$.

The Appendix 4 shows that equilibrium is uniquely determined by equations (6), (10) for $j = 1$, equation (11) for $j = 1, 2, \ldots, n$, the expected present value budget constraints (EPVBC):

$$E_0 \sum_{t=0}^{\infty} \frac{u'(c_{j,t})}{u'(c_{j,0})}\delta^t \Big(c_{j,t} + d k_{j,t-1}(1-\tau^k) - r_t k_{j,t-1}(1-\tau^k)$$
$$- w_t\, \mu^t \phi_1\, l_{j,t}(1-\tau^l) \Big) = m_{j,-1} \quad \text{for} \quad j = 1, 2, \ldots, n-1 \tag{12}$$

$$E_0 \sum_{t=0}^{\infty} \frac{u'(c_{1,t})}{u'(c_{1,0})}\delta^t \left(g_t - (r_t - d)\, k_{t-1}\tau^k - w_t\, e_t \tau^l \right) = m_{g,-1} \tag{13}$$

and a constant λ_j such that

$$\frac{u'(c_{j,t})}{u'(c_{n,t})} = \lambda_j \qquad \text{for all } t \text{ for } j = 1, 2, \ldots, n-1 \tag{14}$$

This reduces the number of equations that need to be checked in equilibrium.[13]

Equation (14) expresses the familiar condition that, with complete markets and common discount factors, the share of output that each agent obtains is constant. The constant λ_j determines this share; for example, if u has a constant relative risk aversion parameter equal to γ_c, agent j, for $j = 1, 2, \ldots, n-1$ obtains a fraction $\zeta_j \equiv (n\lambda_j^{\frac{1}{\gamma_c}})/(1 + \sum_{i=1}^{n-1} \lambda_i^{\frac{1}{\gamma_c}})$ of total consumption in all periods while agent n obtains a fraction $n/(1 + \sum_{i=1}^{n-1} \lambda_i^{\frac{1}{\gamma_c}})$. Except for some special cases where aggregation obtains[14], λ_j depends on the tax rates and on the initial distribution of wealth; in turn, aggregate variables depend on this constant. The fact that constants λ_j and g are endogenous to the tax system, adds to the difficulties of finding a numerical solution (point iii) in the introduction).

4 Some Stylized facts and Analytic Results

For the rest of the paper we assume the following functional form of the utility function:

$$u(c) = \frac{c^{\gamma_c+1}}{\gamma_c+1} \quad \text{and} \quad v(l; \mu^t) = B\,\frac{(1-l)^{\gamma_l+1}}{\gamma_l+1}\,\mu^{t(\gamma_c+1)}$$

for $\gamma_c; \gamma_l < 0$ and $B > 0$; and we assume that hours worked satisfy $0 \leq l_{j;t} \leq 1$: Introducing human capital in this form in the utility function insures that the solution for leisure is not degenerate in steady state. For most of our simulations we take $\gamma_c = -1$, a case in which the term $\mu^{t(\gamma_c+1)}$ disappears.

First of all, we mention two simple empirical observations:

a) variability of aggregate consumption across time is lower than variability of aggregate hours worked.

b) variability of consumption across individuals of different wealth is higher than variability of hours worked.

These observations are supported by casual empiricism; they have also been documented formally by many authors. For example, Hansen [1985] documents fact a).

Fact b) is documented by our Table 1. This table reports several statistics on individual variables from a representative sample of households in the PSID data set. Households are split in five income-groups according to two different criteria; the precise method for splitting the sample will be discussed in detail in subsection 5.2. It can be seen that, under both criteria, the ratio of hours worked of any group respect to type five agents is much closer to one than the ratio of consumption.[15]

Fact a) has to do with how the hours worked in the economy react to a temporal change in production, while fact b) has to do with the wealth-elasticity of hours worked. The policy experiment that we are considering will cause both a change over time of aggregate hours worked and a redistribution of wealth so that, ideally, we would like to have a model and parameter values that agree with both of the above observations.

We now study the equilibrium of the model for particular values of the parameters. The derivations in this section are quite simple, and they are spelled out here for future reference. They will be useful when we select parameter values in the next section.

For the rest of this section we make the simplifying assumption that $\mu = 1$ and $m_{g;-1} = m_{j;-1} = 0$: Also, subsections 4.1 and 4.2 below assume $\psi_i = \psi_j = \psi$ for $i; j = 1; 2; \ldots; n$.

4.1 Linear utility of leisure

Hansen [1985] and Rogerson [1986] showed that fact a) above can be explained if leisure enters linearly in the utility function, to set $\gamma_l = 0$; they also showed how this utility arises in a model with indivisible labor and lotteries.

Nevertheless, this parameter value implies in our model that,

$$c_{i;t} = c_{j;t} \qquad \text{for all } t; \text{ and for } i; j = 1; 2; \ldots; n$$

This can be obtained from (11) and simple algebra. This is incompatible with fact b); in this case, the model predicts that agents with the same efficiency of labor but different levels of wealth consume the same amount, and higher wealth is only used to enjoy a higher level of leisure.

4.2 Gorman Aggregation

Consider now the case that $\gamma_c = \gamma_l$. Here, the economy behaves as if there were a representative consumer, and aggregate variables are unaffected by distribution of wealth.

First of all, observe that equations (14) and (11) imply

$$c_{j;t} = \eta_j \, c_t \qquad \text{and} \qquad 1 - l_{j;t} = \eta_j (1 - l_t) \quad \text{for} \quad j = 1; 2; \ldots; n \tag{15}$$

where η_j for $j = 1; 2; \ldots; n$ are defined in section 3.2; so that individual consumption and labor are fixed proportions of the aggregates. It is easy to check that all equilibrium conditions described in the previous section hold if individual quantities are replaced by aggregate quantities. In order to solve this model, one can first solve for the aggregate quantities and then find the individual quantities with (15).

All that is left to compute are the constants η_j. From aggregate allocations we substitute (15) into equation (12) and obtain

$$\eta_j = \frac{k_{j;-1} E_0 \left[\sum_t \delta^t c_t^{\gamma_c} (r_t - d)(1 - \tau^k) \right] + E_0 \left[\sum_t \delta^t c_t^{\gamma_c} \phi \, w_t (1 - \tau^l) \right]}{E_0 \left[\sum_t \delta^t c_t^{\gamma_c} \left(c_t + \phi \, w_t (1 - l_t)(1 - \tau^l) \right) \right]} \quad \text{for} \quad j = 1; 2; \ldots; n \tag{16}$$

This gives us an expression for η_j (and, therefore, λ_j) that depends only on aggregate variables calculated beforehand, and the initial distribution of wealth.

This example brings about two points: first, equation (16) is an explicit expression for the weight η_j, and it shows that this weight is endogenous to the tax system. Second, in this case the variability of consumption and hours worked are equal, as can be seen from equation (15). Therefore, in this case both facts a) and b) are violated.

4.3 Proportional wealth

Consider the case where the efficiency of labor and the initial wealth of agent 1 are higher than agent 2's, agent 2's higher than 3's, etc., but all in the same proportion, so that

$$\frac{\phi_i}{k_{i;-1}} = \frac{\phi_j}{k_{j;-1}} \quad \text{for} \quad i; j = 1; 2; \ldots; n \tag{17}$$

Also, assume that $\gamma_c = -1$.

Given any feasible fiscal policy $(\tau^l; \tau^k; g)$, equilibrium allocations satisfy

$$\frac{c_{i;t}}{c_{j;t}} = \frac{\phi_i}{\phi_j} \quad ; \quad l_{i;t} = l_{j;t} \quad \text{for all} \quad t; \; i; j = 1; 2; \ldots; n \tag{18}$$

This can be easily derived from the first order conditions for optimality. Therefore, in this case $\lambda_j = \phi_j / \phi_n$ independently of tax policies, so that the share of consumption of each agent is invariant to changes in taxes. Also, as in the previous case, it is easy to show that we have perfect aggregation.

Since λ_j is independent of tax rates, any gain or loss in aggregate consumption is shared between all agents. If aggregate consumption changes due to a change in tax rates, all agents gain or loose in the same amount.

If, in addition to the assumptions in this subsection we add the assumption that γ_l is close to zero, we could explain both facts described above. Furthermore, this example shows that it is possible to find parameter values for which the distribution of consumption is not affected by tax policies. Nevertheless, assuming proportional wealth is not a satisfactory approximation to the heterogeneity observed in the actual economy. This can be seen in Figure 1, which plots wages against wealth for different households in a representative sample (see discussion in subsection 5.2); the dispersion of wage/wealth ratios is clearly very high, while equation (17) implies that most points in that figure would lie close to a ray going through the origin. This analysis shows that it is very important for our purposes to calibrate the parameters from individual income appropriately. Also, it shows that the wage/wealth ratio is what determines if an agent gains or looses from a policy change, so that this ratio is the appropriate criterion for splitting the sample of households that are likely to be affected by the policy change in a similar way into two groups.

5 Parameter Choice and Solution Algorithm.

We choose parameter values in order to match some basic empirical observations on aggregate quarterly time series, such as stylized fact a), as well as observations at the micro level, as stylized fact b).

We assume the usual Cobb-Douglass production function normalized to account for balanced growth: $F(k_{t-1}; e_t; \theta_t) = {}^{1\alpha} k_{t-1}^{\alpha} e_t^{1-\alpha} \theta_t$.

We now describe the choice of parameter values for the benchmark case.

5.1 Utility and Technology parameters

With the exception of γ_l, we choose values in the benchmark case for utility and technology that are standard in the real business cycle literature. This makes the results comparable with the rest of the literature; it also insures that our model matches some first and second moments of aggregate time series. Notice that, since we introduce depreciation allowances, it is important to model growth explicitly in order to distinguish between gross and net investment.

The utility function depends on parameters, γ_c, γ_l and B. As in Cooley and Hansen, we use log-utility of consumption, so that $\gamma_c = -1$, and we choose B in order to have the representative agent working 1/3 of his time endowment in the deterministic steady state. The parameters of the production function are chosen to match the labor share of income and aggregate fluctuations of output. Depreciation rate, discount rate of utility, and growth rate are set to the usual values for quarterly data. Initial aggregate capital is equal to the mean of capital in the benchmark economy.

The choice of γ_l is particularly important for matching the stylized facts described at the beginning of section 4. Now, the cases studied in sections 4.1 and 4.2 suggest that in order to match fact b) we need to choose $|\gamma_l| > |\gamma_c|$; furthermore, it is easy to check that, for our choice of B,

$$l_{j;t} \to 1/3 \quad \text{as} \quad \gamma_l \to -\infty;$$

for $j = 1; 2; \ldots; n$ and for all t. For our purposes, it seems particularly important to capture how hours worked by agents will react due to a change in capital and labor taxes. For this reason, we choose $\gamma_l (= -10)$, which makes our model close to satisfying fact b).

5.2 Heterogeneity parameters

In our model, agents differ only in the efficiency level of their work ϕ_j and their initial wealth $k_{j;-1}$. It is important to choose these parameters appropriately since in some cases (for example, in subsection 4.3) changing the tax system has no effects on distribution.

Our next task is to split the sample in groups of equal size and calibrate the heterogeneity parameters of each kind of agent with the observations on each group. We choose to work with five groups of equal size as we consider it is a rich enough partition to capture interesting behavioral differences.

First of all, we discuss how the households have been grouped to produce the five representative agents of our model.

In the literature on distribution, households have been often classified as 'rich' or 'poor' according to measures of total income or wealth. However, this is not an appropriate criterion given the experiment we consider: households with relatively low (high) wages compared to their total wealth, i.e., agents with a low (high) wage/wealth ratio $\phi_j/k_{j,-1}$, are likely to gain (loose) from a drop in capital taxation. Figure 1 represents a scatterplot of the households' wage and wealth in the Panel Study of Income Dynamics. Both the households in the upper-left corner and those in the lower-right corner of Figure 1 are 'rich', but those in the upper-left corner are likely to be hurt if capital taxes go down. Our discussion in section 4.3 shows that agents with the same wage/wealth ratio are equally affected by a change in capital taxes.

This is why we split our sample in terms of the wage/wealth ratio identifying the parameters for agents of type j from observations on households with a wage/wealth ratio between the $j-1$ and the j quantile. Figure 1 illustrates graphically the most simple case, where $n = 2$. We seek a ray such that half of the points in Figure 1 are on each side of the ray; the households below the ray represented in that figure correspond to type 1 agents in the model. By contrast, the more traditional criterion of splitting the sample by total income would correspond to splitting the sample with a negatively sloped line, and the 'total wealth criterion' would use a vertical line.

Another complication stems from the fact that our measures are affected by a pure life cycle effect, something that our model does not take into account. For example, older people are usually wealthier than younger people and they are likely to be retired. Almost all of them would belong to group 1, amounting to a high percentage of the sample and leaving little room to representatives of other age groups. To remove that effect from our measures, we first split the sample into six age groups, and divide each age group according to their wage/wealth ratio. The wage of type 1 agents, for example, is calculated with a weighted average of the observed wages of households in the low wage/wealth ratio across age groups; the weights given to each age group correspond to percentages of US population as reported by the Census.[16]. In order to match consumption ratios we proceed similarly.

To summarize, the benchmark heterogeneity parameters are obtained by splitting the sample in five groups with the wage/wealth criterion and eliminating the life-cycle effects. In order to check the robustness of our results, we have also calculated the heterogeneity parameters splitting the sample with a pure wealth criterion (i.e., splitting the sample by means of vertical lines). The statistics obtained from the two possible criteria are reported in Table 1.[17].

Initial wealth is calibrated so as to obtain an implied consumption ratio $c_{j,t}/c_{5,t}$ for $j = 1,\dots,4$ matching the one observed in the data. The PSID does not provide a direct measure of total consumption, but it provides detailed information on asset holdings of different types by the households. We calibrate the consumption ratio by finding the ratio of total labor income plus income that can be obtained from asset holdings. We consider net asset returns, after corporate taxes, depreciation, etc. have been paid, so that this is the capital income that can be used to sustain higher consumption for all subsequent periods in steady state. The net real return assigned to each kind of asset is obtained from a variety of sources; multiplying asset holdings by the corresponding net real return we obtain the net total return to each agent's portfolio. For a more detailed description see Appendix 3.

5.3 Government Parameters.

Finally, we discuss the benchmark choice for the triplet $(\tau^l; \tau^k; g)$.

Since we are particularly interested in the effects of substituting capital taxes by labor taxes, the only kind of government spending that we will consider is the one that comes from these tax revenues. Therefore, total government spending in our model will be lower than the one observed in the economy.

As in most predecessors of this paper, we use the measures of average marginal tax rates calculated with the procedure of Joines [1981]. We use McGrattan, Rogerson and Wright [1997] estimates of $\tau^k = .57$ and $\tau^l = .23$ for the period 1947-87. Government spending is selected to balance the budget with these taxes.

There is considerable disagreement on the relevant level of labor and income taxes, specially on the level of the capital tax; for the latter, Feldstein, Dicks-Mireaux and Poterba [1983] obtain estimates that range between .55 and .85 for the period 1953-1979. Papers also vary on the introduction of depreciation allowances and growth. [18] Hence, our benchmark value is around the middle range of these estimates. We will discuss in detail the sensitivity of our results to the value of τ^k, as we are going to experiment with different levels of capital taxes.

The considerations in this section lead us to choose the list of parameters in Table 2.

5.4 A Solution Algorithm Based on PEA

Given that it is impossible to find analytic solutions under the benchmark parameters, we resort to numerical simulation. The solution algorithm we use is based on the Parameterized Expectations Approach described in Marcet and Marshall [1994]. The problem at hand is: for fixed functional forms and parameter values for preferences and technology, and given two government-policy parameters (for example, τ^k and τ^l), find the equilibrium allocations and a feasible government policy (i.e. government spending g)

The general procedure is, given τ^k and τ^l

- Step a). Fix λ_j for $j = 1, 2 \ldots, n$ and g to some arbitrary levels.
- Step b). Solve for a stochastic process $\left\{\bar{c}_{j;t}; \bar{l}_{j;t}; \bar{k}_t\right\}_{t; j=1;2;\ldots;n}$ that satisfies equations (6), (14), (10) for $j = 1$; and (11) for these values of λ_j and g.
- Step c). Check if expected present value constraints (12) and (13) are satisfied for the stochastic processes found in Step b). If not, iterate on the above steps until values for λ_j and g are found such that EPVBC's are satisfied.

Since, for fixed $\lambda_j; g$; equations (6), (14), (10) for $j = 1$;and (11) are a special case of the stochastic difference equation system described in Marcet and Marshall [1994], Step b) is performed with PEA.

The evaluation of EPVBC introduces another computational difficulty. For this purpose and for finding individual savings we follow Hollyfield, Ketterer and Marcet [1988]. More details are given in Appendix 1.

Finally, since good approximations to non-linear laws of motion can only be found on a finite interval, we need to translate the model with growth into deviations from trend, and solve for the law of motion for these deviations. This is done in the usual (but tedious) way in Appendix 2..

6 Simulations Under Different Tax Systems

6.1 Effects of suppressing capital taxes

The main goal of this paper is to study the welfare effects of eliminating capital taxes. We compare the equilibrium of the model under the benchmark parameters (A) with the equilibrium when $\tau^k = 0$ and labor taxes are increased to maintain the level of government expenditure (B). The behavior of the model under both policies is described by Figures 2 and 3, and Tables 3 and 4.

Figures 2 and 3, contain plots of one typical realization for the series of the model under both policies and for agents of type 1 and 5. For each one of these variables we present two figures: the graphs labelled 'initial periods' cover periods 0 to 100 of the simulation, while the graphs labelled 'steady state' cover periods 1000 to 1100, long after the variable has attained the support of the steady state distribution. Tables 3 and 4 summarize some first and second moments of the solution at the steady state distribution.

The effect on aggregate variables of abolishing capital taxes is clearly to enhance economic activity in the long run. If capital income taxes are suppressed, investment is higher, and consumption and leisure are lower in the first few periods. But we see from Table 3 that the steady state mean of aggregate GNP increases by about 25%, total consumption increases by 16%, investment almost doubles, and wages increase by 28%. All of these indicators would normally be taken as evidence that the economy as a whole benefits from suppressing capital taxes.[19] Not surprisingly, the response of aggregate variables is similar to the effect described in previous studies of models with homogeneous agents.

Nevertheless, the effect on individual decisions is harder to predict from those studies, since the redistributive effect of abolishing capital taxes may offset the higher aggregate production. It is clear that hours worked of low wage/wealth ratio agents are likely to decrease, since both the substitution effect (lower net wages) and the wealth effect (higher wealth from lower capital taxes) work in the same direction, but the effect on most of the other individual variables is uncertain before seeing the calculations. From Figures 2 and 3 it is clear that consumption of agent 1 is much higher in the new steady state, while consumption of agent 5 is lower in all periods. The effect on leisure is similar. These figures anticipate the fact that high wage/wealth ratio agents will loose welfare if capital taxes are abolished.

Table 5 describes aspects of the effect on individual consumers of the tax change. The labor tax rate is 0.37 (up from .23) when capital taxes are abolished; this increase is sufficient to offset the higher wage for agents 4 and 5. This causes changes in the equilibrium weights λ_j and, consequently, drops in the ratios $c_{j,t}/c_{1,t}$, specially large for agents of type 4 and 5 that see their relative consumption to decrease from .55 and .31 to .40 and .17 respectively.

Welfare gains of changing the tax system are evaluated as in previous papers (say, as in Lucas, Cooley and Hansen or Chari, Christiano and Kehoe) by finding the percentage change in consumption that each individual should experience to be as well off as under the benchmark policy, leaving leisure unchanged. More precisely, letting $\tilde{c}_{j,t}, \tilde{l}_{j,t}$ be the equilibrium under the benchmark policy, and $\hat{c}_{j,t}, \hat{l}_{j,t}$ be the equilibrium under the alternative tax policy, the welfare gain is given by π_j that satisfies

$$E_0 \sum_t \delta^t \left(u((1 + \pi_j/100)\,\tilde{c}_{j,t}) + v(\tilde{l}_{j,t}, \mu^t) \right) = E_0 \sum_t \delta^t \left(u(\hat{c}_{j,t}) + v(\hat{l}_{j,t}, \mu^t) \right).$$

Table 5 summarizes the individual welfare and distributional effects of reducing capital taxes to several alternatives between the benchmark case and zero.

These welfare comparisons confirm that a policy change that eliminates capital income taxation at the expense of labor income taxation is not beneficial for all agents in the economy. If capital taxes were suppressed, the distributional issues dominate the gain in aggregate efficiency for a large part of the population, and agents with a high wage/wealth ratio will experience a huge utility loss. The loss in welfare is very high, specially if compared with that reported in recent papers studying the effects of changes in fiscal or monetary policy

6.2 A Pareto improving policy.

We do not conclude from these results on welfare that a policy of high capital taxes, as in the benchmark case, is adequate. Indeed, consider the Laffer curve in Figure 4, relating levels of spending that could be financed with different values of capital taxes (keeping labor taxes at the benchmark level). It can be seen that the current level of capital taxes of $\tau^k = .57$ is close to the top of the Laffer curve, an indication that there may be potential gains from lowering them. But our results point to the fact that, without some explicit redistribution, at least 40% of the population would be against abolishing capital taxes. Interestingly, Table 5 shows that a moderate reduction in capital taxes to $\tau^k = .45$ would achieve a gain in utility for 80% of the agents[20].

An improvement in the welfare of all agents could be achieved with a policy that combined the elimination of capital income taxes with a redistribution of wealth. This policy calls for an expropriation of agents of types 1 to type 4's wealth in the first period; this wealth should then be given to agents of type 5. This total wealth redistribution should be done in such a way that the equilibrium share of output of the new policy does not change the λ_j, to insure that all agents gained if this policy were implemented. We have calculated that, for the benchmark case of Table 2, the Pareto-improving policy achieves a welfare gain for all types of agents of about 5.9%. The size of the expropriation is about 9.4 times the first period's income for type 1 agents, 9.7 for type two agents, 10 for type 3 and 10.5 for type 4 agents. Type 5 agents obtain then a transfer of about 5.5 times their first period's income and the government uses part of the expropriation to pay for present and future expenditures. The labor tax rate is unchanged and capital taxes are suppressed. This example shows that the high levels of the optimal capital taxes in the first few periods, in models with heterogeneous agents, serve the purpose of redistribution of wealth, in addition to the usual Chamley-effect of minimizing the distortions introduced by capital taxation.

6.3 Sensitivity and Empirical performance: An unresolved puzzle.

In order to study the reliability of our results, we end by discussing the sensitivity to changes in parameter values and empirical performance. We have experimented with a wide range of the utility parameters γ_c, γ_l and B. The differences in welfare gains (or losses) were very small among the different specifications, and in all cases the qualitative results remain unchanged.

A crucial parameter for our results came from the criterion we used for splitting our sample of households into five groups of wealth. The benchmark case used the wage/wealth ratio and eliminated life-cycle effects. We have also calculated the welfare gains using different combinations of splitting criteria or life-cycle elimination. As can be seen from the second part of Table 5, the result of large changes in utility are again reinforced if we use other partition criteria.

Finally, we study the sensitivity to the tax levels. There is large discussion in the literature about what is the relevant level of average marginal tax rates. The rate of

$\tau_k = .57$ reported in MacGratten, Rogerson and Wright is not as high as it may appear, since it is applied to income after depreciation allowances and since this is the sum of taxes paid by consumers and firms. Estimates in the literature range from .27 (Chari, Christiano and Kehoe) to .85 (Feldstein, Dicks-Mireaux and Poterba), and therefore our benchmark value stands in the middle; also, some authors do not consider depreciation allowances.

Not surprisingly, if the benchmark parameter for capital tax is lower, the individual welfare gains (or losses) are smaller. Table 6 summarizes individual and aggregate gains in efficiency when the benchmark capital taxes are set at different levels. We define 'aggregate gains' as those that could be achieved with the redistributive policy discussed in the previous subsection. When the initial τ^k is very low the aggregate gains are small, but even then agents of type 5 experience a very high loss.

We end this section by discussing the empirical performance of the model in terms of matching some first and second moments observed in the data. The moments of aggregate variables in the model are summarized in Tables 3 and 7.

We have already pointed out that variability of consumption is lower than variability of hours worked across time, but the opposite is true across agents of different wealth. Unfortunately, this is a puzzle that can not be resolved within the simple framework of our model; either we set $\gamma_l = 0$, (as in Hansen [1985]), to match the time series behavior and fail on the cross section fact, or we choose a high $|\gamma_l|$ (as in this paper) in order to match the cross section behavior; then, Table 3 shows that the volatility of hours worked is very low in our model, so that we fail on the time series dimension. It may be important to study the effects of capital taxation in a model that reconciled these observations, since eliminating capital taxes affects the evolution of hours worked over time as well as across individuals. We do not resolve this issue here because we do not know of a model available in the literature that can resolve this puzzle at this point, and because we wanted to keep our model similar to those used in the recent literature of taxation in dynamic equilibrium models. Several modifications of the model may help in resolving this puzzle; such as introducing time non-separability in leisure, endogenous human capital accumulation, or the introduction of both an intensive and extensive margin in a model with uninsurable risk. These are left for future research.

Roughly speaking, most of the correlations among variables are as in the usual real business cycle models. The main exception (in addition to the low volatility of hours worked discussed in the previous paragraph) is that the correlation of hours worked with GNP is now much lower than in other real business cycle studies; in fact, as can be seen from Table 7, it is slightly negative. It turns out that the value of this correlation is highly sensitive to small changes in the parameters. This sensitivity is due to the low volatility of hours worked, which makes the correlation nearly ill-defined, since both the numerator and the denominator of the correlation now contain very small numbers in absolute value; hence, this negative correlation seems to be driven by the empirical puzzle discussed in the previous paragraph.

7 Conclusion

This paper questions the conclusion that a neoclassical growth model with explicit micro-foundations supports the supply-side view that capital taxes should be abolished. Even though all aggregate indicators of economic activity respond positively to abolishment of capital taxes, the welfare of at least 20% of the population goes down dramatically; sometimes 60% of the population loose. The relevant criterion for determining who benefits from supply-side changes is not total wealth, but the wage/wealth ratio. Agents with a higher wage/wealth ratio experience a large decrease in welfare, while agents with a low wage/wealth ratio would enjoy a large welfare improvement. Therefore, the redistributive e¤ect of abolishing capital taxes strongly dominates the e¢ciency gain in terms of aggregate production in this model, for a large part of the population. This result is robust to changes in the parameters and the criterion for splitting the sample. In order for all types of agents to gain from eliminating capital taxes, as it happens in Chamley and Judd's analysis of the Ramsey equilibrium in heterogeneous agent models, it is important to follow the optimal transition path dictated by the Ramsey problem, and not to implement the long-run optimum from period zero[21] as in our analysis.

We choose the model and the parameter values as close as possible to the traditional neoclassical growth model and real business cycle studies; the conclusion is robust to changes in parameter values along many directions. Even for very low initial values of ¿^{k}, the loss in welfare of the …fth group (the one with the highest wage/wealth ratio) is high.

We …nd that the changes in welfare are large and a¤ect a large part of the population. It is well known that the di¤erence in income between the richest and poorer 20% of the population is very high; for 1992, the ratio of total income between the upper and lower quintile reported by CPS is 12.5; the di¤erences in welfare from being in one or other quintile must be very important. It seems that the problem of distribution of wealth is an important issue, and that dynamic equilibrium models are able to deliver striking results.

It is interesting to see how the e¤ect of suppressing capital taxes on the median voter (our type 3 agent) is often quite small. In fact, whether the median voter would gain or lose from the tax reform, depends very much on the parameter values chosen for the model. So, from the vantage point of traditional political economy, the model does not give strong predictions about whether such tax reform would be approved in a once-and-for-all referendum

Nevertheless, the high welfare loss experienced by type 5 agents is very robust. To the extent that this group represents 20% of the population, it seems clear that most modern democratic societies are unlikely to bear the social con‡icts that are likely to arise from such a tax reform.

The model could be enriched along many directions[22]. In particular, we feel that the puzzle of the variability of consumption and hours worked should be solved. But our purpose here was to stay as close as possible to the standard neoclassical growth model to demonstrate the importance of taking into account the distributional e¤ects of tax reforms.

APPENDIX 1
PEA algorithm

We describe here how to apply PEA to perform Step b) in section 5.4. Given μ, g, τ^k and τ^l, we find $\left\{\bar{c}_{j,t}, \bar{l}_{j,t}, \bar{k}_t\right\}_{t,j=1,2,...,n}$ that satisfy equations (6), (14), (10) for $j = 1$, and (11)

- Step 1; substitute the conditional expectation in the right side of (10) by a flexible functional form of the state variables of the model to obtain

$$u'(\bar{c}_{1,t}) = \delta\, \psi(\beta; \bar{k}_{t-1}, \theta_t) \tag{19}$$

  Here, we choose ψ as an exponentiated polynomial that is insured to take on only positive values; the parameters β are the parameters in the polynomial. Fix β.

- Step 2. Obtain a long simulation $\left\{\bar{c}_{j,t}(\beta), \bar{l}_{j,t}(\beta), \bar{k}_t(\beta)\right\}^T_{t=0,j=1,2,...,n}$, consistent with this parameterized expectation for large T. This is done by, in each period, for given state variables, obtaining $\bar{c}_{1,t}(\beta)$ from (19), $\bar{c}_{j,t}(\beta)$ for $j = 2, ..., n$ from (14); $\bar{l}_{1,t}(\beta)$ and $\bar{l}_{j,t}(\beta)$ for $j = 1, 2, ..., n$ from (11); finally, $\bar{k}_t(\beta)$ is obtained from (6) and we can move to the next period.

- Step 3. Perform a non-linear regression of

$$u'(\bar{c}_{1,t+1}(\beta)) \left((\bar{r}_{t+1}(\beta) - d)(1 - \tau^k) + 1\right)$$

  (the expression inside the conditional expectation in (10)) on the functional form

$$\psi(\cdot; \bar{k}_{t-1}(\beta), \theta_t).$$

  Call the result of this regression $G(\beta)$

- Step 4. Iterate on β to find $\beta_f = G(\beta_f)$.

The approximate solution is given by $\left\{\bar{c}_{j,t}(\beta_f), \bar{l}_{j,t}(\beta_f), \bar{k}_t(\beta_f)\right\}^T_{t=0,j=1,2,...,n}$

In the case that the initial capital stock is away from the steady state distribution of capital (as when taxes change), Step 2 has to be modified by, instead of running one long simulation for large T, run many short run simulations based on independent realizations of the stochastic shock. More precisely, we draw N independent realizations $\{\theta_{t,n}\}^{T',N}_{t=0,n=1}$ and substitute Step 2 by

- Step 2'. Obtain simulations $\left\{\bar{c}_{j,t,n}(\beta), \bar{l}_{j,t,n}(\beta), \bar{k}_{t,n}(\beta)\right\}^{T',N}_{t=0,n=1,j=1,2,...,n}$, consistent with this parameterized expectation for large N, starting all simulations at fixed initial conditions, and using the steady-state β_f to solve the series at $t = T'$.

as is done, for example, in Marcet and Marimon [1992].

In order to evaluate the expectations involved in EPVBC, for example in (12), one could draw N realizations of length T'' and approximate the conditional expectation

$$\frac{1}{N} \sum_{n=1}^{N} \sum_{t=0}^{T''} \frac{u'(\bar{c}_{1,t,n})}{u'(\bar{c}_{1,0,n})} \delta^t \left(g - (\bar{r}_{t,n} - d)\, \bar{k}_{t-1,n}\, \tau^k - \bar{w}_{t,n}\, \bar{e}_{t,n}\, \tau^l\right)$$

here, N and T'' both have to be large. It turns out that this approximation necessitates extremely large T''; the reason is that when capital taxes are lowered, the government accumulates large amounts of debt, and interest payments in the steady state are very high. Since N has to be large, it would be computationally costly to also set T'' very large; in order to obtain accurate solutions for low T'' we add to each element in the above sum

$$\frac{\beta^{T''}}{u'(\overline{c}_{1;0})} E_t \left(\sum_{i=0}^{\infty} \beta^i u'(\overline{c}_{1;t+i}) \left(g - (\overline{r}_{t+i} - d)\, \overline{k}_{t-1+i}\, \tau^k - \overline{w}_{t+i}\, \overline{e}_{t+i}\, \tau^l \right) \right) \tag{20}$$

which approximates the tail of the infinite sum. The conditional expectation can be easily approximated by parameterizing the conditional expectation in (20) with a flexible functional form in the steady state, using long run simulations.

Assuming that N is large enough, this method for evaluating EPVBC eliminates inaccuracies by letting T'' be large and by letting the polynomial that parameterizes the expectation in (20) be of high order. By comparison, Cooley and Hansen relied only on T'' being very large (since they did not use (20)), which was computationally feasible due to the fact that they were using a deterministic model. Chari, Christiano and Kehoe relied only on the conditional expectation being well approximated (since their method amounts to using $T'' = 1$); by comparison, our evaluation of the EPVBC is much less affected by miscalculations of the nonlinearities of the savings functional around the initial condition, and it does not need to iterate in order to find this functional.

APPENDIX 2
Introducing Balanced Growth

We show how the equilibrium in the model in the paper can be converted into a stationary model, by removing growth from the solution. This is a necessary step for obtaining nonlinear approximations to the law of motion. The formulas can be derived with simple but annoying algebra; they are offered to save the reader some time and because the depreciation allowances introduce some differences with the case of no taxes.

Let the deviations from growth be given by

$$\tilde{c}_{j,t} = c_{j,t}/\mu^t \qquad \tilde{i}_t = i_t/\mu^t \qquad \tilde{k}_t = k_t/\mu^t \tag{21}$$

and so on. We want to find equilibrium conditions expressed in terms of these variables; we'll see that the resulting equilibrium conditions can be interpreted as arising from a purely stationary model with the exception of the way depreciation allowances enter the model.

Substituting the variables using formula (21) in the equilibrium conditions one obtains the following: the production function given by

$$\tilde{c}_t + g + \tilde{i}_t = \tilde{F}(\tilde{k}_{t-1}, \tilde{l}_t; \theta_t) = \tilde{k}_{t-1}^{\alpha}\, \tilde{l}_t^{1-\alpha}\, \theta_t$$

satisfies feasibility condition, and $\tilde{r}_t = \tilde{F}_1(\tilde{k}_{t-1}; \tilde{l}_t; \theta_t) = r_t/\mu$ and $\tilde{w}_t = \tilde{F}_2(\tilde{k}_{t-1}; \tilde{l}_t; \theta_t) = w_t$. Given the utility function introduced in section 4, hours worked satisfy

$$\tilde{c}_{j,t}^{\gamma_c}\, \tilde{w}_t\, (1-\tau^l)\phi_j - B(1-l_{j,t})^{\gamma_l} = 0 \tag{22}$$

Therefore, hours worked are stationary and we can take $\tilde{l}_t = l_t$. On the other hand, letting $\tilde{\beta} \equiv \delta\mu^{\gamma_c+1}$, and $\tilde{d} \equiv 1-(1-d)/\mu$, the transition for capital, first order condition for capital, and EPVBC's can be written as

$$\tilde{k}_t = \left(1-\tilde{d}\right)\tilde{k}_{t-1} + \tilde{i}_t$$

$$\tilde{c}_{j,t}^{\gamma_c} = \tilde{\beta} E_t\left(\tilde{c}_{j,t+1}^{\gamma_c}\left((\tilde{r}_{t+1} - d/\mu)(1-\tau^k) + 1/\mu\right)\right) \tag{23}$$

$$E_0 \sum_t \left(\frac{\tilde{c}_{j,t}}{\tilde{c}_{j,0}}\right)^{\gamma_c} \tilde{\beta}^t \cdot \Big(\tilde{c}_{j,t} + \tilde{d}\tilde{k}_{j,-1} - \tilde{k}_{j,-1}(\tilde{r}_t(1-\tau^k)$$

$$+\tau^k d/\mu) - \phi_1 \tilde{w}_t\, l_{j,t}(1-\tau^l)\Big) = \tilde{m}_{j,-1}/\mu \quad \text{for} \quad j = 1, 2, \ldots, n-1. \tag{24}$$

for the government's EPVBC

$$E_0 \sum_t \left(\frac{\tilde{c}_{1,t}}{\tilde{c}_{1,0}}\right)^{\gamma_c} \tilde{\beta}^t \left(g - (\tilde{r}_t - d/\mu)\,\tilde{k}_{t-1}\tau^k - \tilde{w}_t\,\tilde{l}_t\tau^l\right) = \tilde{m}_{g,-1}/\mu. \tag{25}$$

Finally, total utility is given by

$$E_0 \sum_t \tilde{\beta}^t\left[\, u(\tilde{c}_{j,t}) + v(\tilde{l}_{j,t}; 1)\,\right] = E_0 \sum_t \tilde{\beta}^t\left[\, u(c_{j,t}) + v(l_{j,t}; \mu^t)\right] \quad \text{for} \quad j = 1, 2, \ldots, n.$$

Notice that, as in the no-government model, deviations from an exogenous trend can be interpreted as a purely stationary model with utility discount factor given by $\tilde{\delta} = \delta \mu^{\gamma_c+1}$; depreciation rate $\tilde{d} = 1 - \mu^{-1}(1 - d)$; and using μ to normalize the returns on capital; the exception is that only a portion $1/\mu$ of the depreciation of the deviations can now be claimed as allowance, so that in the Euler equation (23) and the budget constraints depreciation allowances enter as a function of d and μ, but not of $\tilde{d}$. Intuitively, the reason for this difference is that in the purely stationary case all investment can be claimed as a depreciation allowance, but if growth is taken explicitly into account, a fraction μ^{-1} of the new capital is not tax deducible.

APPENDIX 3

Data used in the calibration of the heterogeneity parameters

We have used the Panel Study of Income Dynamics (PSID) to obtain several distributive measures involved in the calibration of the model. This is a well known data set that collects information on families and their offspring. We select families that were interviewed and that kept the same head from 1984 to 1989.

Our agents in the model will be households in the data, and not the different individuals that compose them. The reason for that lies in the difficulty to extract individual values from family aggregates.[23]

The variables we want to calibrate are the efficiency parameters ϕ_j, and the value of the initial capital stocks $k_{j,-1}$ for $j = 1, 2, \ldots, 5$. As discussed in section 5.2, we need estimates of wages and returns from assets.

The PSID provides measures for average hourly wages, labor income, and several categories of non-human wealth and asset income. We use the reported measures of asset returns whenever these are available,averaging asset income or rates of return over the last five years of the sample period. Otherwise we multiply each asset's value by average long-run net rate of return as reported in several studies.

In what follows we specify how we treat each particular component of non-human wealth.

1. Types of assets for which the PSID reports asset returns.

    - Net value of Business or Farms, market and gardening activities , or rooming and boarding activities.
    - Cash assets (savings and checking accounts, CD's, IRA's, etc.) and dividends.

2. Types of assets for which we impute an asset return.

    Here we multiply the current value of the asset held by an average (over five years) real rate of return. The following is a list of these assets and the return series we use.

    - Net value of Bonds, Insurance Policies and Collectible Goods: Moody's average corporate bond yield[24].
    - Stocks, Mutual Funds: S&P'S common stock price index. (Dividends are reported as asset income in the category of 'cash assets').
    - Total real estate[25] : we use the value calculated in Rosenthal [1988, p 95]. Rents perceived by the families are already embedded in that rate of return, therefore we do not use the rents reported in the PSID, as to avoid double counting.
    - Pensions and Annuities: we use the US Government Security Yield, 10 years or more, Treasury compiled.
    - Other Debts: we use the secondary market yields on FHA mortgages since this is composed, mostly, of second mortgages.

We deflate these nominal returns or rates by the wholesale consumer price index. The PSID also reports the net value of autos, mobile homes etc. We do not impute any rent for this category.

APPENDIX 4
Characterization of equilibrium

The following proposition reduces the number of equilibrium conditions; this simplifies greatly the calculation of equilibrium.

Proposition 1 Given tax rates τ^k, τ^l, if a unique equilibrium exists and it is interior, then the equilibrium process for $\{c_{j,t}, l_{j,t}, k_t\}_{j,t}$ and the equilibrium value of g are determined uniquely by the following conditions:

- equation (6), equation (10) for $j = 1$ and equation (11) for $j = 1, 2, \ldots, n$
- there is a constant λ_j for $j = 1, \ldots, n-1$ such that equation (14) holds for all t.
- expected present value budget constraints, equations (12) and (13) are satisfied.
- $\left\{ c_{j,t}/\mu^t, l_{j,t}, k_t/\mu^t \right\}_{j,t}$ is a stationary process

Proof of Proposition 1

First, we show that (14) is necessary and sufficient for (9). From (9) we obtain

$$\frac{u'(c_{j,t})}{u'(c_{n,t})} = \frac{u'(c_{j,t+1}(\theta))}{u'(c_{n,t+1}(\theta))}$$

for $j = 1, 2, \ldots, n-1$ and for all t and θ; this implies that the ratio of marginal utilities at t is equal to the ratio at $t-1$ with probability one. By induction $u'(c_{j,0})/u'(c_{n,0}) = u'(c_{j,t})/u'(c_{n,t})$ for all t; since the consumptions at $t = 0$ are independent of the realization for the stochastic process, we have equation (14). On the other hand, for the contingent claim prices q that satisfy (9) for $j = 1$, (14) implies that (9) is satisfied for $j = 2, \ldots, n$ so that (14) implies (9) for $j = 1, 2, \ldots, n$.

Clearly, (14) together with (10) $j = 1$, are necessary and sufficient for (10) $j = 2, \ldots, n$.

With concave utility and production functions, if an equilibrium with interior solutions exists and is unique, the solution to the maximization problem of consumers and firm is uniquely determined by first order conditions and the transversality condition, so that the above conditions are sufficient for maximization of utility and profits.

Now we show that the EPVBC's are a necessary condition for the period–by-period budget constraints (for more details see Hollyfield, Ketterer and Marcet [1988]). Applying forwards recursion to (1) and using (9) to substitute for the prices of contingent claims, we find (13) and

$$E_0 \sum_t \frac{u'(c_{j,t})}{u'(c_{j,0})} \delta^t \Big(c_{j,t} + i_{j,t} - r_t k_{j,t-1} + (r_t - d) k_{j,t-1} \tau^k - \phi_j w_t \mu^t l_{j,t} (1 - \tau^l) \Big) = m_{j,-1} \quad \text{for} \quad j = 1, 2, \ldots, n-1$$

In order to drop the terms $k_{j,t-1}$ from these equations we can set $k_{j,t-1} = k_{j,-1}$;and $i_{j,t-1} = dk_{j,-1}$ for all t to obtain (12). Since the individual choice for capital holdings is arbitrary, this substitution is valid. Also, a similar constraint for agent n is satisfied by Walras' law.

Finally, we show that EPVBC are sufficient for the period-by-period budget constraints. For example, contingent claims holdings for the government are given by

$$m_{g,t-1}(\theta) = E_0 \left[\sum_i \frac{u'(c_{1,t+i})}{u'(c_{1,t})} \delta^i \left(g_{t+i} - (r_{t+i} - d)\, k_{t-1+i} \tau^k - e_{t+i} w_{t+i} \tau^l \right) \middle|\, \theta = \theta_t, \theta_{t-1}, \theta_{t-2}, \ldots \right]$$

(end of proof)

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Notes

[1]Notable exceptions are Judd [1985], Krusell and Rios [1994] and McGrattan [1993]. Also Heathcote and Domeij [2000] have introduced incomplete markets in a model similar to the present paper.

[2]Also, in the framework of optimal taxation, we know that capital taxes should be zero in the long run, but the transition must take care of the redistributive issues; this transition would be ignored if capital taxes are eliminated from period zero.

[3]Depending on the exact parameterization, the percentage of the population that looses may go up to 60%. In other parameterizations 40% looses. The huge loss of 20% of the population is highly robust.

[4]We solve the model with the Parameterized Expectations Approach (PEA) described in Marcet and Marshall [1994].

[5]Strictly speaking, these papers show that, under uncertainty, the optimal tax on capital may not be zero at all periods in the long run. Nevertheless, the optimal tax is still small in absolute value and, in fact, taxes are negative in some periods.

[6]These papers argue that in endogenous growth models with human capital, labor should not be taxed in the long run either. Nevertheless, optimal taxation with human capital su¤ers from time inconsistency in the same way that taxation of physical capital does, (see next paragraph).

[7]Klein and Ríos-Rull [2000] …nd than when the government can not commit beyond the next period, optimal capital income taxes are very high.

[8]There are other di¤erences with Krusell and Ríos-Rull' model, for example, they study the trade-o¤ between income taxes and lump-sum redistribution, not between capital and labor taxes. Also, they introduce incomplete markets.

[9]Introducing growth in‡uences the e¤ect of depreciation allowances, since total investment would be equal to gross investment when there is no growth. We introduce growth as in Chari, Christiano and Kehoe.

[10]Strictly speaking, some additional constraint has to be introduced in order to rule out Ponzi schemes. This can be accomplished by imposing an upper limit on the amount of contingent claims that can be sold, such that the limit is never binding in equilibrium. The same will be true for the budget constraint of the government.

[11]Since we maintain g constant across policy experiments, the equilibrium computed and the welfare gains discussed in section 6 are consistent with a model where government spending enters the utility function or the production function; to keep notation simple, we write the paper as if government spending had no productive use.

[12]That is, given information at t and a possible value μ, the expression $c_{j;t+1}(\mu)$ represents a number, while $c_{j;t+1} \equiv c_{j;t+1}(\mu_{t+1})$ is a random variable.

[13]In particular, it means that equations (10) for $j = 2; \ldots; n$, equation (9), period-t budget constraints (1) and (5) can be ignored when solving for consumption, labor, capital and government spending.

[14]See subsections 4.2, 4.3.

[15]We are, by no means, the …rst to report this particular fact. For example, Kydland [1984] reports a similar observation. The advantage of Table 1 is that it con…rms the usual observation when the sample is split according to the criteria discussed in subsection 5.2.

[16]The six age groups are as follows: Less than 25 years old (14.4% of U.S. population), from 25 to 34 (with 23.32% of the population), from 35 to 44 (20.30%), 45 to 54 (13.62%), 55 to 64 (11.43%) and older than 64 (with a 16.89% of total U.S. population).

[17]These consumption ratios can only be sustained if wealth of some of the agents is higher than total capital. This happens because, in the real world, assets such as land play a very important role in the portfolios of individuals. Modelling land ownership and land rental appropriately may be important for

the issues we discuss, but its introduction goes beyond the scope of this paper. We simply assume that some agents hold enough contingent claims to maintain the consumption ratio observed in the data.

[18] For example, Cooley and Hansen use a lower tax rate, setting ¿^{k} = :5, (this number is based on Joines [1981] with the data ending in 1979), and they do not substract growth from the depreciation allowances; Chari, Christiano and Kehoe use ¿^{k} = :27; Lucas [1990] considers capital and labor taxes of .4; Greenwood, Rogerson and Wright [1995] set ¿^{k} = :70.

[19] Subsection 6.2 provides a more concrete measure of aggregate welfare gains within the model.

[20] It must be pointed out, though, that this feature is highly sensitive to small changes in the parameter values.

[21] Chari, Christiano and Kehoe also point out the importance of following the transition of optimal taxes in a homogeneous agent model.

[22] See for example, Heathcote and Domeij [2000] for a model with incomplete markets …xed labor supply, and where inequality is not calibrated according to wage/wealth ratios.

[23] The PSID provides some individual variables, but it is by no means comprehensive.

[24] All rates of return or price series were extracted from CITIBANK.

[25] As the di¤erence between real estate value and principal mortgage remaining.

Table 1: Means and ratios in the groups of the PSID sample

Wage/Wealth criterium						
	Means by type			Type i over type 5 ratios		
Type	Hours	Wage	Perm. Income	Hours	Wage	Consumption
1	2708.03	7.89	58611.94	1.315	1.048	3.241
2	2837.86	11.11	50397.86	1.378	1.475	2.787
3	2468.28	9.72	37822.32	1.199	1.291	2.092
4	2333.49	9.4	31790.4	1.133	1.248	1.758
5	2059.41	7.53	18083.11	-	-	-
Wealth criterium						
	Means by type			Type i over type 5 ratios		
Type	Hours	Wage	Perm.Income	Hours	Wage	Consumption
1	3031.43	15.04	84644.67	1.597	2.549	5.708
2	2858.14	10.31	45058.34	1.505	1.747	3.039
3	2520.16	7.99	31277.28	1.327	1.354	2.109
4	2098.94	6.48	21047.11	1.106	1.098	1.419
5	1898.61	5.9	14828.54	-	-	-

*The benchmark case corresponds to the wage/wealth ratio criterium. Type 1 corresponds to households with a lower wage/wealth ratio while type 5 corresponds to the higher one. When splitting the sample by total wealth, type 1 households are those with higher wealthwhile type 5 are the ones with lower wealth. See subsection 5.2 for a full discussion.

Table 2: Parameter values of the benchmark economy

®	.36	$¿^l$	.23
±	.99	$¿^k$	.57
d	.02	¹	1.004
$°_c$	-1	½	.95
$k_{¡1}$	6.7	$¾^2_{²}$	.01
$°_l$	-10	$m_{g;¡1}$	-2.0
Heterogeneity parameters			
Wage/Wealth Partition		Wealth Partition	
$Á_1$=$Á_5$	1.05	$Á_1$=$Á_5$	2.55
$Á_2$=$Á_5$	1.48	$Á_2$=$Á_5$	1.75
$Á_3$=$Á_5$	1.29	$Á_3$=$Á_5$	1.35
$Á_4$=$Á_5$	1.25	$Á_4$=$Á_5$	1.10
$k_{1;¡1}$=$k_{¡1}$	6.30	$k_{1;¡1}$=$k_{¡1}$	6.15
$k_{2;¡1}$=$k_{¡1}$	2.07	$k_{2;¡1}$=$k_{¡1}$	1.50
$k_{3;¡1}$=$k_{¡1}$	0.25	$k_{3;¡1}$=$k_{¡1}$	0.20
$k_{4;¡1}$=$k_{¡1}$	-0.91	$k_{4;¡1}$=$k_{¡1}$	-0.32

Table 3: First and second moments of aggregate variables

	Benchmark Economy			Zero capital Tax		
	$¿^k$ = 0:57			$¿^k$ = 0		
Variable	Mean	Std. Error	Volatility	Mean	Std. Error	Volatility
k	6.77	0.47	0.07	13.12	0.64	0.04
i	0.16	0.02	0.13	0.31	0.03	0.10
GNP	0.99	0.05	0.05	1.24	0.06	0.04
l	0.33	0.0009	0.0027	0.33	0.0011	0.0034
c	0.58	0.03	0.05	0.67	0.03	0.04
w	1.89	0.09	0.05	2.42	0.11	0.044
r	0.05	0.002	0.03	0.03	0.0010	0.03
$¿^l$	0.23	-	-	0.37	-	-
g	0.25	-	-	0.25	-	-

Table 4: Means of individual consumption and leisure(*)

Variable	Wage/Wealth Partition		Wealth Partition	
	Benchmark	Zero Capital Tax	Benchmark	Zero Capital Tax
c_1	0.83	1.16	1.22	1.55
c_2	0.72	0.86	0.65	0.76
c_3	0.54	0.60	0.45	0.49
c_4	0.45	0.47	0.3	0.32
c_5	0.26	0.2	0.21	0.16
l_1	0.29	0.27	0.31	0.3
l_2	0.33	0.32	0.33	0.32
l_3	0.34	0.33	0.34	0.33
l_4	0.35	0.35	0.34	0.34
l_5	0.37	0.39	0.37	0.39

(*) These, and all the moments in the rest of the tables, are for the steady-state distribution.

Table 5: Welfare gains in benchmark case

¿^{k}	Wage/Wealth Partition				
	¼$_1$	¼$_2$	¼$_3$	¼$_4$	¼$_5$
0.57	-	-	-	-	-
0.456	7.30%	3.68 %	1.95%	0.17%	-6.68%
0.342	13.23%	6.33 %	2.84%	-0.70%	-12.06%
0.228	18.48%	8.11 %	2.87 %	-2.48%	-19.40%
0.114	23.50%	9.39 %	2.28%	-4.93%	-27.53%
0	28.36%	10.35 %	1.31%	-7.84%	-36.10%
¿^{k}	Wealth Partition				
	¼$_1$	¼$_2$	¼$_3$	¼$_4$	¼$_5$
0.57	-	-	-	-	-
0.456	5.49%	3.29 %	1.89%	0.73%	-6.87%
0.342	9.59%	5.50 %	2.77%	0.54%	-14.03%
0.228	13.02%	6.85 %	2.76%	-0.60%	-22.32%
0.114	16.05%	7.68 %	2.15%	-2.33%	-31.33%
0	18.85%	8.15 %	1.11%	-4.56%	-40.67%

¿^{k}	Wage/Wealth Partition							
	$\frac{c_2}{c_1}$	$\frac{c_3}{c_1}$	$\frac{c_4}{c_1}$	$\frac{c_5}{c_1}$	$\frac{1 ¡ l_2}{1 ¡ l_1}$	$\frac{1 ¡ l_3}{1 ¡ l_1}$	$\frac{1 ¡ l_4}{1 ¡ l_1}$	$\frac{1 ¡ l_5}{1 ¡ l_1}$
0.57	0.86	0.65	0.55	0.31	0.95	0.93	0.93	0.89
0.456	0.83	0.61	0.51	0.28	0.95	0.93	0.92	0.88
0.342	0.81	0.59	0.48	0.25	0.95	0.93	0.91	0.87
0.228	0.79	0.57	0.46	0.22	0.94	0.93	0.91	0.87
0.114	0.77	0.54	0.43	0.20	0.94	0.92	0.90	0.85
0	0.74	0.52	0.40	0.17	0.94	0.92	0.90	0.84
¿^{k}	Wealth Partition							
	$\frac{c_2}{c_1}$	$\frac{c_3}{c_1}$	$\frac{c_4}{c_1}$	$\frac{c_5}{c_1}$	$\frac{1 ¡ l_2}{1 ¡ l_1}$	$\frac{1 ¡ l_3}{1 ¡ l_1}$	$\frac{1 ¡ l_4}{1 ¡ l_1}$	$\frac{1 ¡ l_5}{1 ¡ l_1}$
0.57	0.53	0.37	0.25	0.18	0.98	0.96	0.96	0.91
0.456	0.52	0.36	0.24	0.16	0.97	0.96	0.96	0.91
0.342	0.51	0.35	0.23	0.14	0.97	0.96	0.95	0.90
0.228	0.51	0.34	0.22	0.13	097	0.96	0.95	0.89
0.114	0.50	0.33	0.21	0.12	0.97	0.95	0.94	0.88
0	0.49	0.32	0.21	0.11	0.97	0.95	0.94	0.87

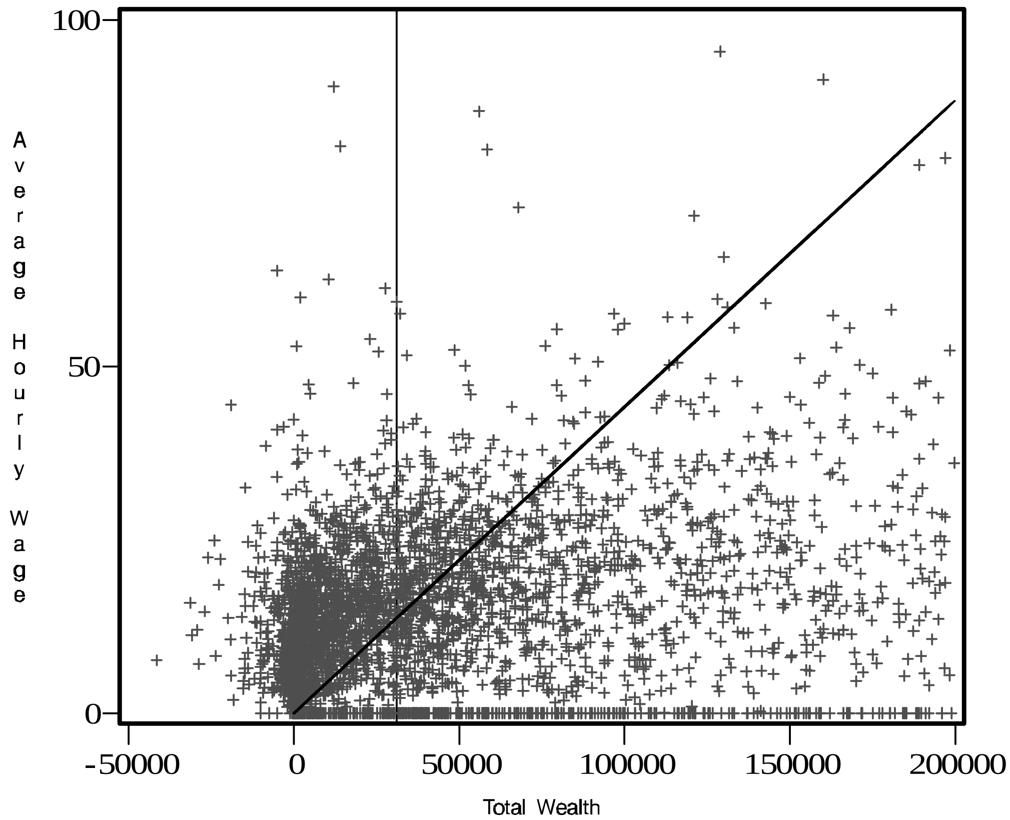
Table 6: Sensitivity of aggregate and individual welfare gains of suppressing capital taxes for different initial τ_k

Initial τ_k	Aggregate	π_1	π_2	π_3	π_4	π_5
0.2	0.034%	6.99%	1.48%	-1.45%	-4.57%	-15.56%
0.3	0.56%	11.16%	2.71%	-1.67%	-6.26%	-21.94%
0.4	1.60%	16.57%	4.61%	-1.37%	-7.55%	-27.85%
0.5	3.72%	22.48%	7.47%	-0.02%	-8.07%	-32.98%
0.6	7.24%	31.41%	11.89%	2.19%	-7.57%	-37.51%
0.7	14.67%	43.99%	19.19%	7.24%	-4.59%	-39.34%

Table 7: Correlations

	Benchmark Economy	Zero Capital Tax
k-i	0.53	0.49
GNP-l	-0.19	0.19
GNP-c	0.97	0.92
w-l	-0.23	0.13
r-i	0.22	0.57
k-k_{-1}	0.999	0.999
GNP-GNP_{-1}	0.98	0.97

Figure 1: Sample distribution of wealth and wages



Note: The (non-human) wealth and wage ranges have been chosen to leave out 12% of the sample. We exclude these outliers from the picture to allow for a better graphical representation. The vertical and positively sloped lines shown in the picture divide the whole sample in two halves for each criterion.

Figure 2: Simulated paths

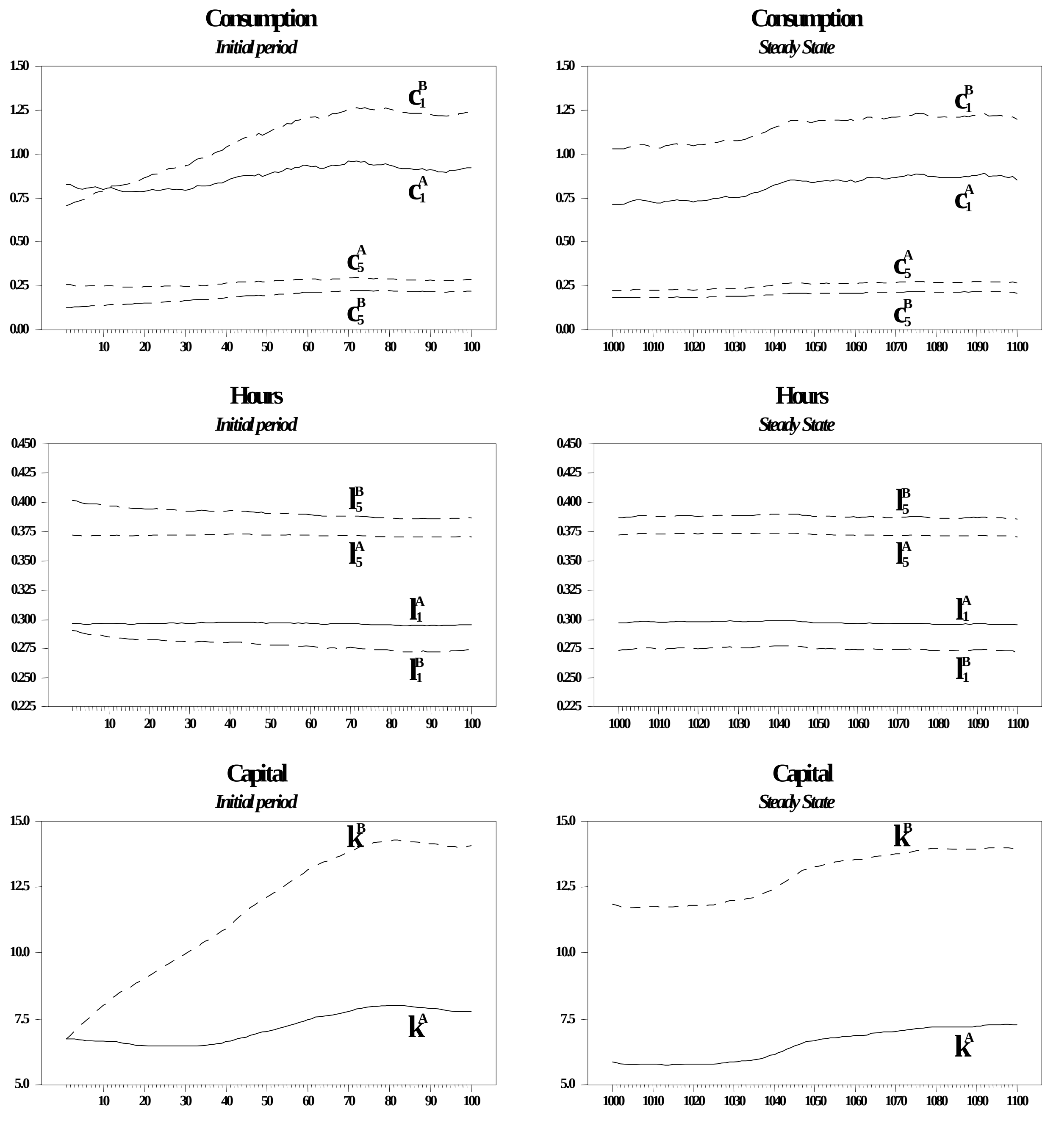


Figure 3: Simulated paths

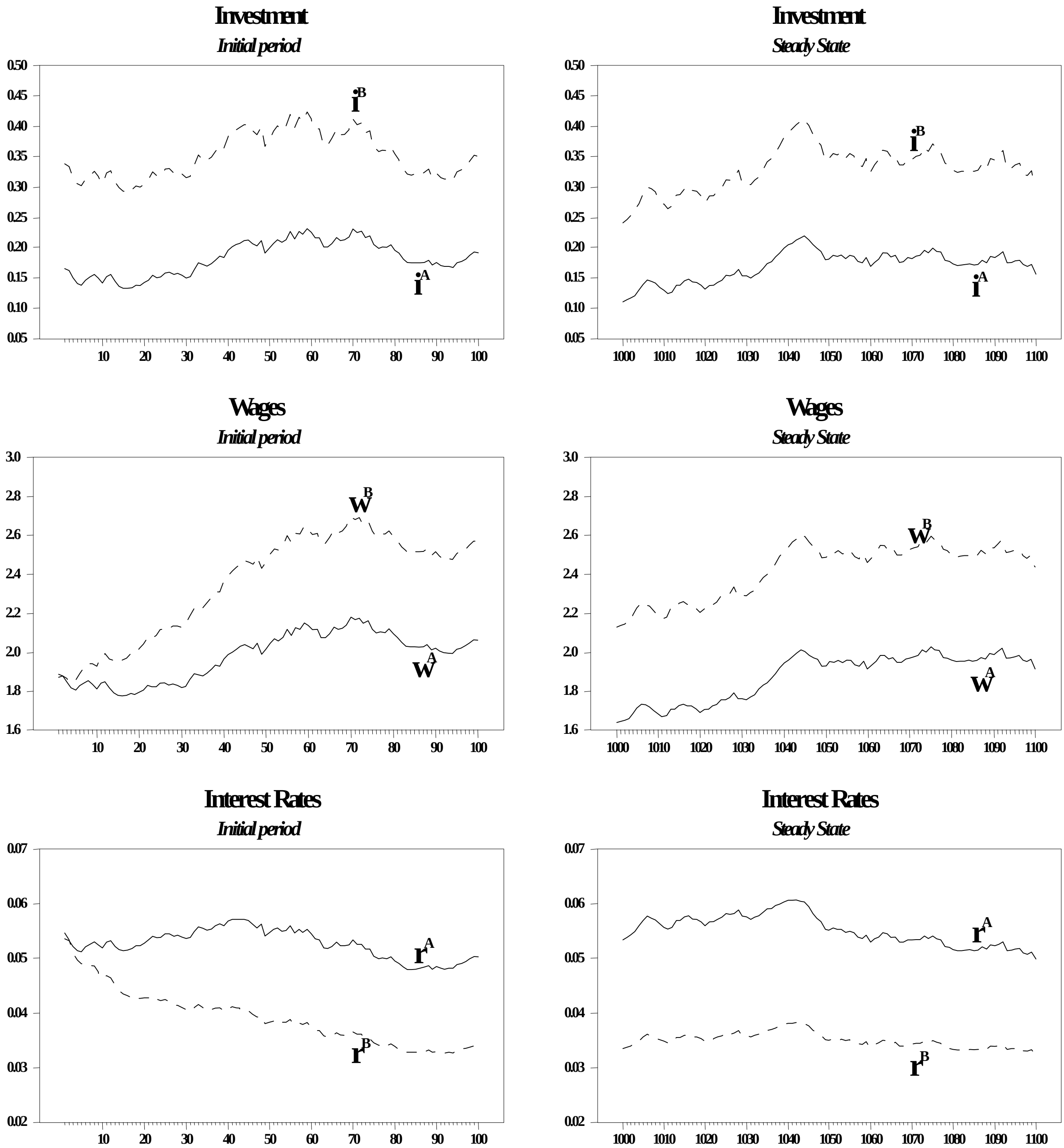


Figure 4: La¤er curve: spending