Why do income and productivity differ in OECD countries?

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Abstract

This paper analyzes to what extent heterogeneity in tax rates on labor/consumption and capital simultaneously can account for observed differences in hours worked per person, capital stocks, productivity and GDP per capita in 15 OECD countries. A multi-country-endogenous-growth model is set up wherein labor supply, capital accumulation and productivity levels are all endogenous. The results show that differences in tax rates go a long way in explaining the large differences in hours worked, capital stocks, GDP/hour, total factor productivity and GDP per capita within OECD countries.

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1 Introduction

It has been well documented that the per-capita income differs substantially across countries. A typical example to illustrate this is that GDP/capita is more than 30 times higher in the richest countries than in the poorest countries.[1] The large literature on development accounting has not only documented these large differences, but has also tried to assess whether the differences are mainly due to differences in factor accumulation or differences in total-factor-productivity (TFP).[2] Even though there has been some disagreement about the relative importance of these two factors, a robust finding is that TFP differences are important for understanding income differences.[3] Caselli (2005) summarizes the literature by stating that "a typical finding is that differences in efficiency account for at least 50 percent of differences in per capita income".

Development accounting is a useful tool for starting to think about income differences across countries. There are, however, at least two limitations associated with most of the studies that have employed this method. First, labor is generally measured by the economically active population and not by actual hours worked per person, as it should preferably be.[4] This may potentially overestimate the role of productivity in accounting for income differences, in particular since labor supply also differs substantially across countries. Second, development accounting cannot uncover the reasons *why* factor accumulation and efficiency differ across countries and hence, it cannot explain why some countries are richer than others. In fact, differences in TFP are sometimes referred to as a measure of our ignorance.

In this paper, I ask the following quantitative question: to what extent can

[1] Acemoglu (2009).

[2] See, for example, Mankiw, Romer and Wei, (1992), Klenow and Rodrígues-Clare (1997), Hall and Jones (1999), Caselli (2005) and Hsieh and Klenow (2010).

[3] Three papers that stress the importance of factor accumulation are Mankiw, Romer and Weil (1992), Young (1995) and Barro and Sala-i-Martin (1995).

[4] This does not stem from a limitation of the method. Instead, it is due to the ambition of including as many countries as possible in the analysis, and the fact that reliable data on hours worked per person is missing for most countries. However, Caselli (2005) includes total hours worked by the employed into the analysis.

heterogeneity in policy – or more specifically, taxes – account for differences in inputs, productivity and output across 15 OECD countries? Inputs and productivity are measured in two different ways. As a first exercise, I use data from EU KLEMS and OECD to analyze the effect of taxes on hours worked per person, GDP/hour and GDP/capita. These three objects are well measured in the data and GDP/hour can be computed without any estimates of the capital stock as opposed to TFPs.[5] This is an advantage since comparable measures of capital stocks are somewhat problematic even within the OECD. However, I then proceed and employ data from the Penn World Table to evaluate the effects on capital stocks and TFPs. A major advantage of focusing on this specific group of countries is that there exists data on hours worked and other necessary variables needed for the research question. In addition, the problem with measurement errors is likely to be smaller for these countries than for many developing countries.

The paper begins by displaying the data and confirming earlier findings of large variations in labor supply, GDP/hour and GDP/capita. People in Belgium, for instance, work less than 65 percent of what people in the U.S. do. On average, however, a Belgian worker also produces 20 percent more output per hour than an American worker. Large variations in inputs and labor productivity are then naturally associated with a large variation in GDP per capita. A multi-country-endogenous-growth model is set up to quantify the potential influence of taxes. Within this Schumpeterian framework, economic growth is generated by quality improving (or vertical) innovations and the countries are linked by international R&D spillovers. The model also features horizontal innovation, which does not generate growth, but effectively eliminates scale effects with respect to the size of the population.[6] The presence of international knowledge spillovers implies that all countries share the same long-run grow rate. Long-run differences in productivity are, however, endogenous and depend on the incentives to carry out R&D and accumulate capital. The model

[5] TFP and GDP/hour are highly correlated in the data. For instance, according to Hall and Jones (1996), the correlation between TFP levels and GDP per *worker* is 0.94.

[6] Specifically, without horizontal innovation, the growth rate is increasing in the size of the population, which is a feature that lacks empirical support. See Jones (1995a).

builds on Howitt (2000), but it is modified in several dimensions. First, both the savings decision and the labor supply decision are made endogenous to allow policy to influence these margins. Second, the research process is different, third, endogenous horizontal innovation is considered and finally, the model is set in discrete time.

All countries are assumed to be identical in all aspects and the only differences are that they implement different tax rates and have different population growth rates.[7] The model is calibrated to the U.S. and the simple experiment I carry out is to feed the model with estimated tax rates for the countries considered to evaluate to what extent the model can predict the data. Average effective tax rates on labor/consumption and capital are estimated from OECD data on National Accounts and Revenue Statistics.

Theoretically, taxes may influence inputs, productivity as well as output. A capital tax, on the one hand, influences the net interest rate, which has a direct effect on the incentives to carry out R&D and thus, on the relative TFP level. A capital tax also lowers the return to savings and the capital stock. As a result, there is less capital per worker and labor productivity is lower. Tax rates on labor, on the other hand, directly affect the net return to labor which is of first-order importance for workers who consider how much labor to supply.

The results show that tax rates on labor/consumption and capital successfully predict the observed levels of hours worked, GDP/hour and GDP/capita in the 15 countries, with only one exception: Belgium. The other 44 observations are well matched, however. Capital taxes are found to mainly affect GDP/hour while having limited effects on GDP/capita, whereas tax rates on labor/consumption have large effects on labor supply, GDP/hour and per-capita income. For this set of countries where inputs are measured with relatively small measurement errors, income differences are found to be due to differences in inputs, in particular the labor supply. Differences in productivity

[7] Taxes on labor and consumption are identical in the model from an efficiency perspective. The term labor tax thus here refers to the combined effects of the labor tax and the consumption tax.

are of less importance in the explanation of observed cross-country differences in GDP/capita.

Using data from the Penn World Table, model predictions for capital stocks and TFP levels are also compared to the data. The results show that there is a strong positive correlation between capital stocks in the model and in the data, but the variance for the predictions are somewhat higher relative to hours, GDP/hour, and GDP/capita. The same is true for TFP levels. The conclusion is that differences in only two tax rates can go a long way in explaining the large differences in hours worked, GDP/hour, TFP and GDP/capita within OECD countries. This conclusion resembles that in Hall and Jones (1999), i.e., that differences in inputs, productivity and output are driven by differences in institutions and government policies. To what extent taxes can also explain differences in inputs, productivity and output for countries outside the sample is an open question left to future research. However, taxes are not likely to be a serious explanation for the large differences in income per capita and growth rates between developed and developing countries.

An important result in the empirical literature is that the marginal product of capital (MPK) is fairly similar across countries.[8] Because of differences in capital taxes, MPKs differ across countries in the model in this paper. However, the model variation is, in fact, somewhat smaller than in the data so the model is not inconsistent with the data in this dimension.

In most of the paper, horizontal innovation is assumed to be exogenous, and this eliminates the scale effects related to the size of the population. In that setting, however, taxes on labor and consumption may affect the global growth rate (because the amount of R&D carried out in a specific country depends on the hours worked per person in that country). Quantitatively, this effect is found to be small, but as a robustness check, I compute the results with endogenous horizontal innovation and find that it does not change the main results of the paper.

The method employed in this paper constitutes an alternative to that used in the development accounting literature. In particular, it provides an expla-

[8] Caselli and Feyrer (2007).

nation for observed differences and it has something to say about when factor accumulation and efficiency should be correlated, which the latter studies are silent about.[9]

This paper is also related to the large literature on the effects of fiscal policy on economic growth,[10] and to the literature that tries to assess the growth effects of tax reform. The model is, in fact, particularly useful for addressing quantitative questions about tax reform, since it matches several relevant features from the real world. As a simple experiment, I compute that the long-run global gross growth rate would increase by 0.1 percentage points if the U.S. were to set their capital tax to zero (and at the same time adjust the labor tax to keep transfers constant). This verifies the findings in Lucas (1990) and Stokey and Rebelo (1995) i.e., that the growth effects of tax reforms are small.

As far as I know, this is the first paper that simultaneously tries to account for observed cross-country differences in inputs, relative productivity and output. In doing so, it sets up a fairly simple model that abstracts from potentially important features. For instance, it assumes that the only connection between the countries is technological spillovers. Thus, it abstracts from all kinds of trade. An important step for future research is to extend the analysis to include trade in one or several goods.

This paper is structured as follows. Section 2 presents the data, Section 3 sets up the model and Section 4 presents the results. Section 5 compares the model and actual interest rates and discusses the effects of human capital. Section 6 carries out a sensitivity analysis and Section 7, finally, computes the growth effects of a simple tax reform.

[9] Hall and Jonas (1996) argue that the main identifying assumption in Mankiew, Romer and Weil (1992), i.e., that productivity differences are uncorrelated with physical and human capital across countries, is violated by the data. Klenow and Rodríguez (1997) also document that productivity and inputs are highly correlated across countries. Caselli (2005) and Hsieh and Klenow (2010) both argue that factor accumulation and efficiency are likely to be correlated and that the same ultimate causes probably explain both.

[10] For instance, Easterly and Rebelo (1993), Mendoza, Milesi-Feretti and Asea (1997), Easterly, Kremer and Pritchett (1993) and Jones (1995). See also Backus, Kehoe and Kehoe (1992) and Jones (1995a, 1995b) on (the non-existence of) scale effects.

2 The Facts

Figure 1 shows data on hours worked per person aged 15-64, GDP per hours worked and GDP per capita for 15 OECD countries. The data on total hours worked is from the EU KLEMS database.[11] This number is then divided by the number of people aged 15-64 to get the hours worked per person aged 15-64. The data on population is from the OECD Employment and Labor Statistics database and the data on GDP is from the OECD National Accounts database. GDP/hour is computed as GDP per hours worked per person aged 15-64. All numbers are averages over the period 1998-2007 and they are expressed as ratios relative to the U.S.

The first bar shows hours worked per person, and it confirms the findings in several recent papers, i.e., that the amount of market work differs considerably across the OECD countries.[12] People in Belgium, for instance, work less than 65 percent of what people in the U.S. do. The second bar shows GDP/hour. The variation in overall productivity is also large, albeit somewhat lower than the variation in hours worked (measured by the coefficient of variation) and even though the average worker in Belgium supplies less labor than the average U.S. worker, the Belgian worker is actually more than 20 percent more productive than the American worker. The third bar, according to which the countries are ranked, shows GDP/capita. Clearly, large variations in both hours worked and labor productivity are associated with a large variation in GDP/capita. In fact, the per capita income in Belgium and France is 62 and 70 percent, respectively, of the per-capita income in the U.S.

Figure 7 (in the Appendix) shows the evolution of the three variables for the period 1980 and 2007 and it shows that the differences in Figure 1 are roughly constant over time. There are some minor individual movements between the countries, but they basically follow parallel growth paths, suggesting that the countries have reached their steady states and that they grow at a common

[11] The variable denoted "H_EMP" is used, which denotes total hours worked by persons engaged.

[12] See, for instance, Prescott (2004), Ragan (2005), Rogerson (2004, 2008) and Olovsson (2009, 2012).

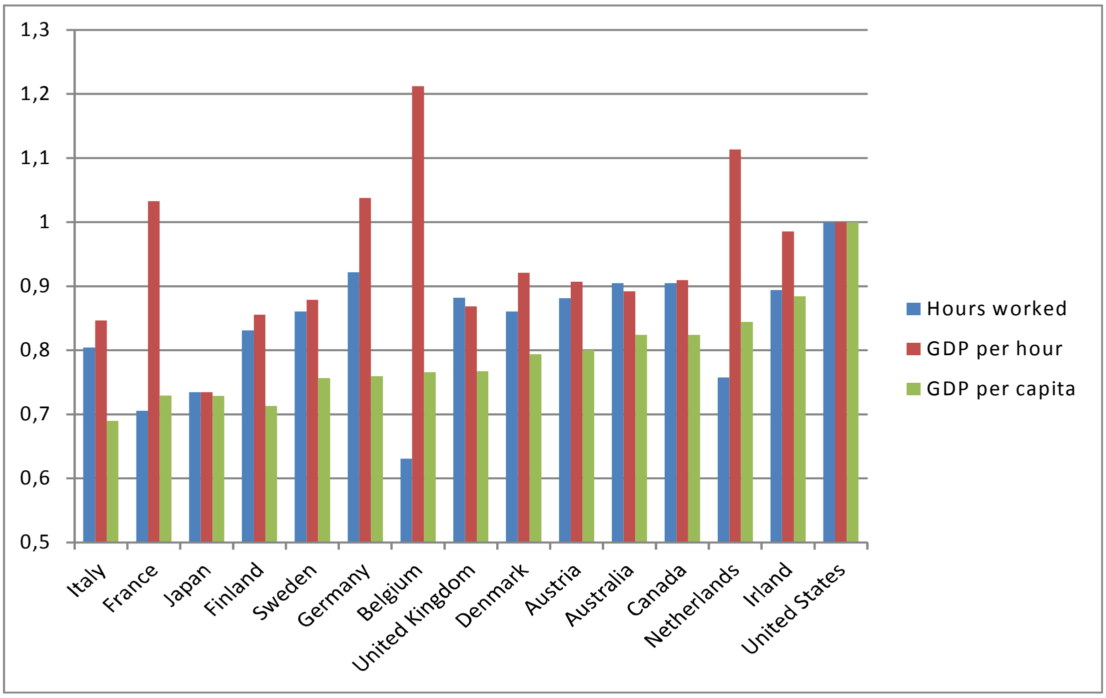

Figure 1: Hours worked per person aged 15-64, GDP per hour and GDP per capita in 15 OECD countries. All numbers are averages over the period 1998-2007 and they are ratios relative to the U.S. The data on GDP and population is from the OECD database and the data on hours worked is from the EU KLEMS database (November 2009).

world rate.[13] The rest of the paper sets up a model and analyzes to what extent the observations in Figure 1 can be explained by differences in tax rates. Unfortunately, I have not been able to find equally good and comparable OECD data on capital stocks. Reliable estimates for capital stocks are necessary for computing total factor productivity (TFP) measures. Comparable estimates for the capital stock are difficult, first because there is more than one type of capital measure and each measure corresponds to a different analytical usage. Second, specific national assumptions underlying their compilation make their international comparability uncertain. For this reason, the first part of the analysis focuses on GDP/hour instead of TFP. Section 4.2, however, uses data from the Penn World Table to compute measures of capital stocks and TFP.

[13] The figure thus verifies the evidence in Evans (1996) that shows that the dispersion of GDP per capita across advanced countries shows no tendency to rise over time.

The model results are then also compared along these dimensions.

3 The Model

This section sets up the basic model. All agents are assumed to be identical and only balanced growth paths (BGP) are considered. The reason is the evidence presented in Figure 7, in combination with the fact that all countries considered are mature and highly developed economies, which are likely to have reached their steady states. Focusing on steady states does then not seem too restrictive for this set of countries.

Consider now a single country in a world economy with M different countries. Time is discrete but since only BGPs are considered, time subscripts are omitted. There is one final good and as in Howitt (2000), it is produced by labor and a continuum of intermediated goods according to the following production function

$$Y = \left(H^F\right)^{1-\alpha} Q^{\alpha-1} \int_0^Q A_i x_i^\alpha di, \tag{1}$$

where Y is gross output, H^F is the aggregate labor supply devoted to the production of final output and Q is the number of intermediate products produced and employed in the country. x_i is the output flow of intermediate product $i \in [0, Q]$ and A_i is the productivity parameter associated with the latest version of intermediate product i. The multiplication by $Q^{\alpha-1}$ in the production function (1) implies that horizontal innovation does not affect aggregate productivity. There is perfect competition in the final goods sector.

The population is assumed to grow at the fixed proportional rate, g_N. Here, the number of intermediate products is, for simplicity, assumed to grow as a result of "accidental" imitation, i.e., imitation just happens. Imitation (or horizontal innovation) creates new sectors and it does not require any resources. Moreover, it is limited to domestic intermediate products. Each person is assumed to have the same propensity to imitate and the aggregate flow of new products is formally given by the following law of motion

$$Q' = \lambda_0 N, \tag{2}$$

where $'$ refers to the value in the next period. The implication of (2) is that the number of sectors grows at the same rate as the population. Specifically, the number of workers per sector will converge to the constant $\theta = N/Q$ (with $\theta \equiv g_N/\lambda_0$) and it is assumed that this convergence has already occurred so that $N = \theta Q$. The production function in combination with the fact that population growth induces a growing product variety ensures that the model does not feature the type of scale effects that Jones (1995a) argues to lack empirical support. Specifically, a larger population does not raise the incentives to carry out R&D by increasing the size of the market.[14] Horizontal innovation is included in the model for the sole reason to kill the scale effect, and it is therefore modeled in the simplest possible way. Endogenous horizontal innovation is, however, considered in section 6.[15]

Capital is assumed to fully depreciate between any two periods so that the aggregate resource constraint for the above economy is given by

$$C + K' = Y. \tag{3}$$

A representative firm in the final good sector solves the following maxi-

[14]The reason is that each innovation is restricted to a single intermediate good and the number of buyers does not increase with the size of the population. This type of model still has scale effects with respect to the *growth rate* of the population (see, for instance, Aghion and Howitt, 1998 and Howitt, 1999).

[15]Zeng and Zhang (2002) and Peretto (2003) both show that for an economy in autarky, taxes that affect the labor supply do not have any long-run implications for the country's growth rate because changes in the effective labor supply lead to changes in product proliferation that exactly offset the scale effects that were caused by the changes in the labor supply. In the model considered here, taxes that influence the labor supply affect the country's relative productivity, but the correlation tax rates and growth rates are zero, because all countries grow at the same global rate and that rate is determined by factors in all countries. This motivates the more simple framework.

mization problem

$$\pi_i = \max_{H^F, x_i^\alpha} \left(H^F\right)^{1-\alpha} Q^{\alpha-1} \int_0^Q A_i x_i^\alpha di - \int_0^1 p_i x_i - WH^F,$$

where p_i is the price of intermediate good i. The resulting first-order conditions then yield the demand for labor and intermediate good i:

$$W = (1-\alpha)\left(H^F\right)^{-\alpha} Q^{\alpha-1} A_i \int_0^Q x_i^\alpha, \tag{4}$$

$$p_i = \alpha A_i \left(H^F\right)^{1-\alpha} Q^{\alpha-1} x_i^{\alpha-1}. \tag{5}$$

Innovations consist of the invention of a new variety of an intermediate good that makes the old one obsolete. A firm that succeeds in innovating gets a monopoly on its product until it gets replaced by the next innovation. It is assumed that A_i units of capital are needed for the monopolist in sector i to produce at the rate x_i. Newer technologies are thus more capital intensive. Capital is rented from the households in a perfectively competitive market and the rental rate is ξ. The average cost of capital is then ξA_i, and the profit maximization problem for the monopolist is given by

$$\pi_i^M = \max_{x_i} \alpha A_i \left(H^F\right)^{1-\alpha} Q^{\alpha-1} x_i^\alpha - \xi A_i x_i.$$

The first-order condition with respect to x_i can be shown to imply

$$x \equiv x_i = \left(\frac{\xi}{\alpha^2}\right)^{\frac{1}{\alpha-1}} \left(\frac{H^F}{Q}\right). \tag{6}$$

Note that x only depends on aggregates, implying that all sectors produce the same amount at any given point in time. At the aggregate level, the demand for capital must equal the supply of saving, i.e., we must have $K = \int_0^Q A_i x_i di$. Furthermore, since x is the same in all sectors, we must also have

$$x = k = K_t / Q_t A_t. \tag{7}$$

The interpretation of (7) is that the equilibrium flow of intermediate output from each sector must equal the capital-intensity per sector. Using equation (7) in the production function delivers

$$Y = \left(AH^F\right)^{1-\alpha} (K)^{\alpha}, \tag{8}$$

implying that the production function is effectively a standard Cobb-Douglas function in capital and labor. Combining equations (6) and (7) delivers that ξ is given by

$$\xi = \alpha^2 \left(\frac{\theta h^F}{k}\right)^{1-\alpha}, \tag{9}$$

where h^F is labor supply per person. The wage rate and profits can then be written as

$$W = A(1-\alpha)\left(\frac{\theta h^F}{k}\right)^{-\alpha} \tag{10}$$

and

$$\pi^M = A(1-\alpha)\,\alpha\left(\theta h^F\right)^{1-\alpha} k^{\alpha}. \tag{11}$$

Finally, since the rental rate of capital is $r + \delta = \xi$, the interest rate is given by

$$r = \alpha^2 \left(\frac{\theta h^F}{k}\right)^{1-\alpha} - \delta. \tag{12}$$

3.1 Technological Progress and Worldwide Growth

There is a separate research sector for each intermediate good. Even though arrival rates in different sectors are independent of each other, the innovations all draw on the same pool of technological knowledge. At any date, there is a worldwide leading-edge technology parameter denoted by $\overline{A}$. Each innovation in any sector at any given point in time allows the innovator to start producing in sector i by using $\overline{A}$. The technology in sector i evolves according to[16]

$$A_i = \begin{cases} \overline{A} & \text{with probability } \mu_i \\ A_{i,-1} & \text{with probability } 1-\mu_i, \end{cases}$$

where subscript -1 refers to the value in the previous period. The productivity parameter thus equals $\overline{A}$ in the fraction of sectors that has innovated in the period $t-1$ and it equals $A_{i,-1}$ in the sectors that did not innovate. In equilibrium, the probability of innovation is the same in each sector, i.e.,: $\mu_i = \mu$ for all i and since innovations are randomly distributed across sectors, the average value of $A_{i,-1}$ is $A_{-1} \equiv \int_0^Q A_{i,-1} di$. The law of motion for average productivity then evolves according to

$$A = \mu\overline{A} + (1-\mu)\, A_{-1}. \tag{13}$$

A country's normalized productivity can be defined as $a \equiv A/\overline{A}$, so that normalized productivity is an inverse measure of a country's distance to the technological frontier. Dividing both sides of (13) by $\overline{A}$, gives

$$a = \mu + (1-\mu)\, \frac{a}{g}, \tag{14}$$

where $g \equiv \overline{A}/\overline{A}_{-1}$ is the world rate of technological progress, which is endogenous but viewed as exogenous by all agents in individual countries. Because the prospective payoff to research is the same in all sectors, the same amount of labor will be used for research in each sector. The probability that an innovation occurs is assumed to depend on a country's relative productivity and the amount of labor used for research per sector, i.e.,

$$\mu = a\theta h^R, \tag{15}$$

where h^R is hours per capita devoted to R&D.[17] The multiplication by a

[16] The process for A_i resembles that in Aghion, Howitt and Mayer-Foulkes (2005) who also consider an endogenous growth model in discrete time.

[17] It is common to assume that R&D requires units of the final good as inputs, whereas I instead assume that time or labor is the necessary input. Clearly, both labor and goods are

captures the feature that it becomes increasingly more difficult to innovate when the distance to the technology frontier is larger. Note that both a and h^R are between zero and one.[18] In addition, it is possible to set parameter λ_0 to ensure that the probability $a\theta h^R$ is always between zero and one. By using (15) in (14), we can solve for a country's relative productivity as a function of the per capita amount of research and the world growth rate:

$$a = \frac{1 - \left(1 - \theta h^R\right) g}{\theta h^R}. \tag{16}$$

The growth rate of the world's leading-edge technology $\overline{A}$ is determined by a spillover process. Specifically, the global technology frontier expands because of innovations everywhere and, as a result, this new knowledge can be used in R&D in other sectors and other countries. Since the probability of innovation is the same in each sector and the number of sectors Q grows over time, the flow of innovations in a country $Q\mu$ grows steadily in steady state. It is assumed that the marginal contribution of each innovation to global knowledge falls with the number of products. The growth rate is then given by

$$g = \sum_{j=1}^{M} \frac{\sigma_j}{Q_j} Q_j a_j \theta h_j^R, \tag{17}$$

where the spillover coefficients σ_j are all non-negative. For simplicity, also assume that the spillover coefficients σ_j are the same for every country. Using (16) in (17) delivers that the global growth rate can then finally be written as:

$$g = \frac{\sigma M}{1 + \sigma \sum_{j=1}^{M} \left(1 - \theta_j h_j^R\right)}. \tag{18}$$

Equation (18) shows that the global growth rate is increasing in the time allocated to R&D in each country (as should be expected).[19]

used as inputs into R&D in the real world. I have solved a version of the model where the final good is used as an input and the results are similar for the two specifications.

[18] Agents are assumed to have one unit of time in each period, implying that h^R is between zero and one. Moreover, all countries will have a relative productivity level of strictly less than one since no country will have the frontier technology in all its sectors.

[19] As in Howitt (2000), the growth rate is also increasing in the number of countries.

3.2 The Government

The government collects tax revenues and redistributes the proceeds back to the agents lump sum. This formulation implicitly assumes that government consumption is a perfect substitute for private consumption.[20] Assume that the gross capital returns of the government taxes allow us to solve large parts of the model analytically. Formally, the government budget constraint is given by

$$T = \left(Nh^F W + Q\pi^M\right)\tau^w + \tau^c C + \tau^k \xi K, \tag{19}$$

where T is the lump-sum transfer. It is assumed that both the wage and the income from innovations are taxed at the same income tax τ^w. The income tax is then neutral with respect to R&D, which seems realistic as a first approximation. This would also be true if R&D requires units of final output as inputs, or if R&D is done by in-house firms that are subject to a corporate tax, since the corporate tax is generally applied to net profits. Costs for R&D are then partially or fully deductible.[21]

This paper takes into account that revenues may be used in a way that influences labor supply. Specifically, as shown by Ragan (2005), Rogerson (2007) and Olovsson (2009), subsidies to day care and elderly care in the Scandinavian countries effectively reduce the effective tax rates on labor. As a result, the tax distortions on the labor market are partially offset in these countries. The use of revenues is discussed in more detail in section 3.7. This paper abstract from other dimensions where revenues could potentially be important for hours worked and productivity. However, it is, in principle, straightforward to take additional dimensions into account.

3.3 Consumers

The economy consists of an infinite amount of identical agents that live forever. Each of these agents has one unit of time at her disposal in each period, and

[20] Most public expenditures, such as publicly provided education, health care and protection services are substitutes for private consumption.

[21] See Peretto (2006) for a formal analysis applied to the U.S.

this unit can be used to produce final output, to do research or for leisure. The time constraint for one of these agents is then given by

$$h^F + h^R + l = 1.$$

Since all agents are identical, it is possible to formulate the problem for a representative agent. The instantaneous utility function for this representative agent is assumed to be logarithmic in consumption and leisure[22]

$$u(C, l) = \psi \log(C) + (1 - \psi) \log\left(N - Nh^F - Nh^R\right). \tag{20}$$

Income comes from four sources: labor income, profits from the monopolies (which are owned by the agent), government transfers and capital income. The budget constraint for the representative agent is thus given by

$$C = \frac{\left(WH^F + Q\pi^M\right)(1 - \tau^w) + T + \xi\left(1 - \tau^k\right)K - gK}{1 + \tau^c}. \tag{21}$$

The problem for the representative consumer is to maximize the present value of utility with respect to savings and hours worked. The first-order condition with respect to savings yields the following relation

$$g = \beta(1 + r)\left(1 - \tau^K\right). \tag{22}$$

Equation (22) is a standard Euler equation and it implies that the after-tax interest rate is given by

$$r = \frac{g - \beta\left(1 - \tau^K\right)}{\beta(1 - \tau^K)}. \tag{23}$$

The first-order condition with respect to hours worked gives

[22]The logarithmic function is standard in the macroeconomic literature and it implies a high Frisch elasticity of labor supply (see, for example, Prescott, 2004 and Rogerson, 2008). However, Olovsson (2009) shows that a model with home production and a low such elasticity will have similar predictions as the more simple logarithmic utility function. Specifically, agents do then not adjust the margin of labor/leisure but rather the margin between market work and home production.

$$\psi \frac{NW}{C} \frac{1-\tau^w}{1+\tau^c} = \frac{1-\psi}{1-h^F-h^R}, \tag{24}$$

which is also a standard expression that determines the labor/leisure trade off. From (24), it immediately follows that the tax rates τ^w and τ^c have identical implications for labor supply. To simplify the notation, I therefore use the following definition:

$$1-\widetilde{\tau} \equiv \frac{1-\tau^w}{1+\tau^c}.$$

3.4 Equilibrium and Innovation

In a steady-state equilibrium, productivity, the size of the population and the number of sectors grow at rates g, g_L and g_L, respectively. This means that $c \equiv C/AQ$, $k \equiv K/AQ$, and $y \equiv Y/AQ$ are constant on a balanced growth path. By plugging the expressions for T (19), and π^M (11) into the consumer's budget constraint, and using the fact that $K' = gK$ where g is given by (22), steady-state productivity-adjusted consumption, c, can be written as

$$c = \left(\theta h_t^F\right)^{1-\alpha} k^\alpha \left(1-\alpha^2\beta\left(1-\tau^K\right)\right). \tag{25}$$

Combining (25) with the aggregate resource constraint (3) gives that the steady-state productivity-adjusted capital stock is given by

$$k = \theta h^F \left(\frac{\alpha^2\beta\left(1-\tau^K\right)}{g}\right)^{\frac{1}{1-\alpha}}. \tag{26}$$

Intuitively, k is decreasing in the capital tax rate. Using the expression for the wage rate (10) and consumption (25) in (24) gives

$$h^F = \frac{\psi(1-\alpha)(1-\widetilde{\tau})\left(1-h^R\right)}{(1-\psi)\left(1-\alpha^2\beta\left(1-\tau^K\right)\right)+\psi(1-\alpha)(1-\widetilde{\tau})}. \tag{27}$$

Note that equation (27) still contains the endogenous variable h^R. Now, turning to the sector for R&D, we note that the productivity parameter of a firm that innovates equals $\overline{A}$ from the time of the innovation until it is replaced by the next innovator in that sector. The steady-state value of an invention is then

$$V = \frac{\overline{A}\,(1-\alpha)\,\alpha\left(\theta h^{F}\right)^{1-\alpha} k^{\alpha}}{r + a\theta h^{R}}. \tag{28}$$

The value is simply the present value of profits from the time of the innovation to infinity. The discount rate is determined by the interest rate r and the probability of being replaced, $a\theta h^R$. To determine the equilibrium amount of R&D carried out, we note that a marginal unit of labor may be used in the production of final output where it has a value equal to the wage rate. Alternatively, it may be used in R&D where it generates the value V with probability $a\theta h^R$. The research arbitrage equation is then

$$W = a\theta V. \tag{29}$$

Because the world growth rate is determined by R&D in all countries, each country only has a marginal impact on the growth rate. Therefore, I assume that all agents view the global growth rate as exogenous. The research arbitrage equation can then (after some manipulation) be written as

$$h^{R} = \frac{\alpha\theta h^{F}}{g} - \frac{1-\beta\left(1-\tau^{K}\right)}{\theta\beta\left(1-\tau^{K}\right)}, \tag{30}$$

where we used (23). With exogenous horizontal innovation, θ is given and the amount of research undertaken is proportional to the hours worked per person within a country (but it is independent of the size of the population). This is basically a scale effect, but it does not imply that a country with a high h^F will have a higher long-run growth rate than other countries. Instead, it only affects relative productivity a, since all countries are growing at the same long-run rate g. Using (27) in (30) and solving for h^R gives an expression for h^R in terms of the parameters and the global growth rate:

$$h^{R} = \frac{\alpha\theta\psi\,(1-\alpha)\,(1-\widetilde{\tau})}{\Psi_2} - \frac{1-\beta\left(1-\tau^{K}\right)}{\theta\beta\left(1-\tau^{K}\right)}\frac{\Psi_1}{\Psi_2}, \tag{31}$$

where

$$\Psi_1 = (1-\psi)\left(1-\alpha^2\beta\left(1-\tau^K\right)\right)g + \psi(1-\alpha)(1-\widetilde{\tau})\,g \quad \text{and}$$
$$\Psi_2 = (1-\psi)\left(1-\alpha^2\beta\left(1-\tau^K\right)\right)g + \psi(1-\alpha)(1-\widetilde{\tau})(g+\alpha\theta)\,.$$

Finally, it is possible to insert the expression for h^R into (27) to derive the expression for labor in final output in terms of the parameters:

$$h^F = \frac{\psi(1-\alpha)(1-\widetilde{\tau})\left(\frac{1-\beta\left(1-\tau^K\right)(1-\theta)}{\theta\beta\left(1-\tau^K\right)}\right)}{(1-\psi)\left(1-\alpha^2\beta\left(1-\tau^K\right)\right)+\psi(1-\alpha)(1-\widetilde{\tau})\frac{g+\alpha\theta}{g}}. \tag{32}$$

3.5 The Effects of Taxes

Armed with the assumption that agents view the global growth rate as exogenous, it is straightforward to derive analytical results that show that both tax rates have a negative effect on hours in final output and in R&D. Since the expressions are somewhat involved, the calculations have been placed in sections A.1-A.2 in the Appendix. Here, it is just claimed that both taxes reduce market work and R&D hours, i.e., that

$$\frac{\partial h^F}{\partial \widetilde{\tau}} < 0,\ \frac{\partial h^F}{\partial \tau^k} < 0,\ \frac{\partial h^R}{\partial \widetilde{\tau}} < 0 \ \text{ and } \ \frac{\partial h^R}{\partial \tau^k} < 0.$$

In a model with exogenous horizontal innovation, taxes on labor and consumption can thus have a negative effect on R&D. This is not the case with endogenous horizontal differentiation as we will see in section 6.[23]

Inserting the expression for k (26) into the production function and dividing by N gives that GDP/capita is given by

$$\frac{Y}{N} = \overline{A}ah^F\left(\frac{\alpha^2\beta\left(1-\tau^K\right)}{g}\right)^{\frac{\alpha}{1-\alpha}}. \tag{33}$$

GDP/capita is thus increasing in relative productivity a, labor supply

[23] However, the result in section 4 shows that the quantitative effect of taxes on labor/consumption on R&D is small also with exogenous horizontal innovation.

h^F and the capital stock. Since both tax rates decrease all these factors, GDP/capita is decreasing in both tax rates.[24] GDP/hour is instead given by

$$\frac{Y}{N\left(h^F+h^R\right)}=\frac{\overline{A}ah^F\left(\frac{\alpha^2\beta\left(1-\tau^K\right)}{g}\right)^{\frac{\alpha}{1-\alpha}}}{h^F+h^R}. \tag{34}$$

The above expression is slightly more complex, because it contains several endogenous variables, but it is straightforward to differentiate (34) with respect to the tax rates to show that GDP/hour is strictly decreasing in both tax rates. This is proved in section A.3 and this section just concludes that theoretically, taxes on labor/consumption and capital reduce the labor supply, relative productivity, GDP/hour and GDP/capita.

3.6 Diminishing Marginal Probability of Innovation

In the previous sections, the probability of an innovation in each sector is assumed to be proportional to the per-capita hours spent in R&D. This is a useful simplification, since it allows for (almost) closed form solutions for h^R and h^F.[25] However, for the numerical analysis, I allow for a diminishing marginal probability of innovation and instead assume the probability to be given by

$$\mu=a^{\phi}\theta h^R, \tag{35}$$

with $0<\phi<1$. Note that since a is a function of h^R, the marginal probability of innovation is now a concave function.[26] The resulting expressions for a country's relative productivity are then implicitly given by the following expression.

[24] It is straightforward to verify that a is decreasing in both tax rates. First differentiate (16) with respect to h^R to derive the effect of R&D on relative productivity $\partial a/\partial h^R=\frac{1}{h^R}\left(\frac{g-1}{\theta h^R}\right)$, which is positive as long as the gross growth rate is larger than one. The effects of taxes on average productivity are then given by $\partial a/\partial\widetilde{\tau}=\left(\partial a/\partial h^R\right)\left(\partial h^R/\partial\widetilde{\tau}\right)<0$ and $\partial a/\partial\tau^k=\left(\partial a/\partial h^R\right)\left(\partial h^R/\partial\tau^k\right)<0$.

[25] Almost, because the expressions still contain the endogenous variable g.

[26] The results are quantitatively similar if we instead assume that $\mu=a\theta\left(h^R\right)^{\phi}$.

With μ given by (35), relative productivity is given by

$$a = \left(\frac{1 - \left(1 - a^{\phi - 1}\theta h^R\right) g}{\theta h^R} \right)^{\frac{1}{\phi}}, \tag{36}$$

and the research arbitrage equation becomes

$$h^R = \frac{a\alpha\theta h^F}{g} - \frac{1 - \beta\left(1 - \tau^K\right)}{\theta\beta\left(1 - \tau^K\right)} a^{1-\phi},$$

where a is given by (36). With this specification, it is no longer possible to solve the model analytically for h^R and h^F. Instead, the model is solved numerically for the rest of the paper.

3.7 Calibration

Even though the benchmark model features several sectors and countries, it only has five parameters (not counting policy instruments and population growth rates). The length of a period is set to ten years. The parameter α determines capital's share of output and it is set to the standard value of 0.3. Parameter β is the discount factor and it is set to 0.80 to generate an annual interest rate around four percent as is standard in the macroeconomic literature. The taste parameter for leisure ψ is set at 0.395 to match the fact that the average American aged 15-64 works 26.54 percent of her total productive time.[27] The spillover coefficient σ is set at 0.99 to generate an annual global growth rate of around 2%. Finally, the parameter ϕ determines the degree of diminishing marginal probability of innovation. It is not obvious how to choose this value, but in the benchmark calibration, it is set to be close to in the middle between zero and one: $\phi = 0.55$. Alternative values for ϕ are considered in the Appendix.

Now turning to the policy instruments, the approach developed by Mendoza et al. (1994) is used to estimate average effective tax rates (AETRs) on labor, consumption and capital. The idea is to directly relate realized tax

[27] Assuming that agents have 100 productive hours per week at their disposal.

rates to the relevant macroeconomic variables in the National Accounts, and this approach is consistent with the concept of aggregate tax rates at the national level and the representative agent framework. The method takes the net effect of existing rules regarding credits, exemptions and deductions into account. It also incorporates the effects of taxes not filed with individual income tax returns. The tax revenue data is from the OECD Revenue Statistics database, which contains information on tax revenues as reported by member countries. As has been shown by Ragan (2005) and Olovsson (2009), subsidies to day care and elderly care in the Scandinavian countries effectively reduce the effective tax rates on labor. Ragan computes the size of the subsidies to be eight percent of consumption for Sweden and Denmark and five percent of consumption for Finland. I follow Ragan and lower the average effective tax rates for the Scandinavian countries by the amount computed in Ragan (2005). The tax rates are computed as averages over the period 1998-2007. The data is from the OECD databases on National Accounts and Revenue Statistics. More details about the estimation procedure are found in section C in the Appendix.

Since essential variables in the National accounts data are missing for Australia, Canada and Japan, these tax rates cannot be estimated. Instead, the tax rates for these countries are taken from Carey and Tchilinguirian (2000). For all estimated tax rates, the variation over time is limited at the aggregate level so hopefully the fact that tax rates for three countries are taken from another study is not to harmful.[28] The estimated tax rates together with the population growth rates are presented in table 1.

The numbers for the population growth rates are taken from the United Nations World Population Prospects Report 2006 (using the medium variant).[29] Finally, the data on hours worked per person, GDP/hour and GDP/capita

[28]The capital tax rate for Japan is set to 0.40 and the average for the periods in Carey and Tchilinguirian (2000) is 0.38. The reason for the slightly higher estimate is that the estimate for Japan's capital tax is substantially higher (in fact, about two times higher) when based on a net operating surplus. In any case, the results in this paper are similar for the two tax rates.

[29]United Nations World Population Prospects: 2006 revision. The numbers in the first column of table A.8 are used.

Table 1: Tax rates and growth rates for the population

Country	$\widetilde{\tau}$	τ^k	g_N
Australia	31.99	25.0	1.0119
Austria	57.05	17.0	1.0044
Belgium	53.49	27.4	1.0040
Canada	38.71	38.0	1.0101
Denmark	48.98	35.1	1.0030
Finland	53.12	22.5	1.0027
France	51.30	24.3	1.0060
Germany	47.50	15.4	1.0008
Ireland	43.20	17.0	1.0171
Italy	51.00	30.0	1.0033
Japan	32.08	40.0	1.0014
Netherlands	49.78	19.5	1.0050
Sweden	53.16	25.7	1.0038
U.K.	35.45	31.9	1.0046
U.S.	29.29	28.8	1.0103

Note: $\widetilde{\tau}$ is the combined tax rate on labor and consumption.

presented in the results section is computed as described in figure 1.

4 Results

The results are presented in figure 2, which shows actual (or observed) values on the horizontal axis and the model predictions on the vertical axis. A perfect fit between the model and the data for a specific country results in a ring exactly on the 45-degree line, whereas a prediction that is lower than in the data produces a ring below the 45-degree line and vice versa. As can be seen, differences in taxes can well predict average annual hours for the 15 OECD countries. Basically all countries line up along the 45-degree line. The subsidies to labor in the Scandinavian countries are important for matching the labor supply in these countries.

The results show that tax rates on labor/consumption and capital also successfully predict the observed levels of GDP/hour in the 15 countries, with only one exception: Belgium. Specifically, all countries except Belgium are scattered along the 45-degree line. Finally, differences in tax rates can also

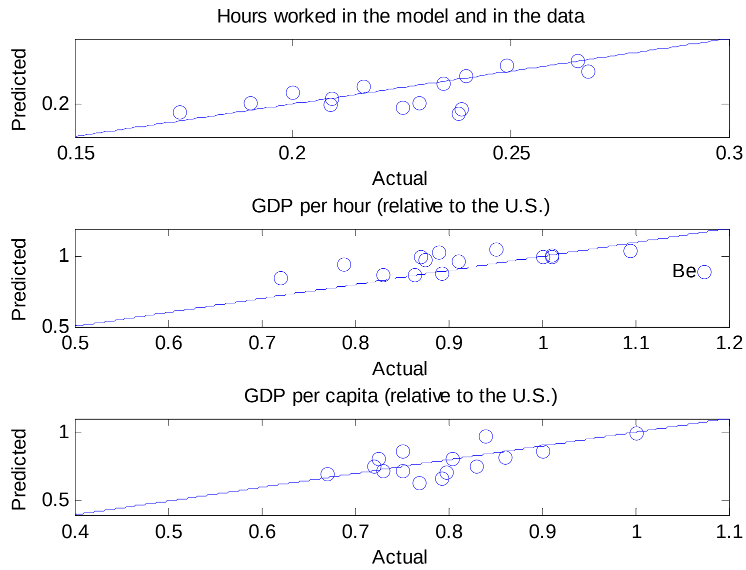

Figure 2: Actual and predicted values for hours worked, GDP per capita and GDP per hour in 15 OECD countries.

quite successfully predict the distribution of GDP/capita. Individual countries deviate from the 45-degree line but overall, there is a close connection between the model and the data.

The European averages relative to the U.S. values are displayed in table 2. The table supports Figure 2 by showing that the model well predicts the data. Europeans work on average 80 percent of what Americans do, GDP/hour in Europe is on average 95 percent of GDP/hour in the U.S., and European GDP/capita is just below 80 percent of GDP/capita in the U.S. These numbers are true both in the data and the model.

Table 2: European averages in the model and in the data

	Hours worked	GDP/hour	GDP/capita
Model	0.77	0.97	0.75
Data	0.81	0.95	0.78

Recall that the 15 countries are identical in all aspects with the only differences being that they implement different tax rates on labor/consumption and capital and that they have different population growth rates. This raises the question of what the individual contribution of each of these three factors is in matching the data? To answer this question, Figure 3 shows the model versus the data for three specific cases. In the first column, the results are shown for the case where τ and τ^k are both constant, but the population growth rates are set as in the benchmark calibration. Clearly, the population growth rates cannot explain anything in this model. Hence, to the extent that the model is successful in accounting for the data, this is entirely due to differences in tax rates. The second column shows the case where $\widetilde{\tau}$ is constant (across countries), but τ^k and the population growth rates are set as in the benchmark calibration. The model can then not match the distribution of hours worked, but it does match GDP/hour. Because hours worked are not matched, the fit for GDP/capita is also bad. In the third column, τ^k is held constant across countries, but $\widetilde{\tau}$ and the population growth rates are set as in the benchmark calibration. The predictions for hours worked and per-capita income are then relatively good but the prediction for GDP/hour is off.[30]

The message from Figure 3 is that even though taxes on labor/consumption and capital affect both labor supply and productivity, the former tax mainly affects the labor supply and GDP/capita while having limited effects on productivity. The opposite is true for capital taxes. Specifically, capital taxes affect the incentives to carry out R&D and accumulate capital and therefore, they mainly affect productivity levels while having a small effect on labor supply (and on per-capita income).

4.1 Inputs versus Productivity

Equation (33) shows that cross-country differences in GDP/capita are due to differences in a, labor supply and the capital stock. What is the relative

[30] Caselli (2005) also considers total hours worked using the LABORSTA database and finds a negative correlation between per-capita income and hours worked. The measure of hours worked in the LABORSTA database is average hours worked per worker and not per person. Differences in employment to population ratios then translate into measurement errors. In the OECD, the correlation between per-capita income and hours worked per person is positive (around 0.40).

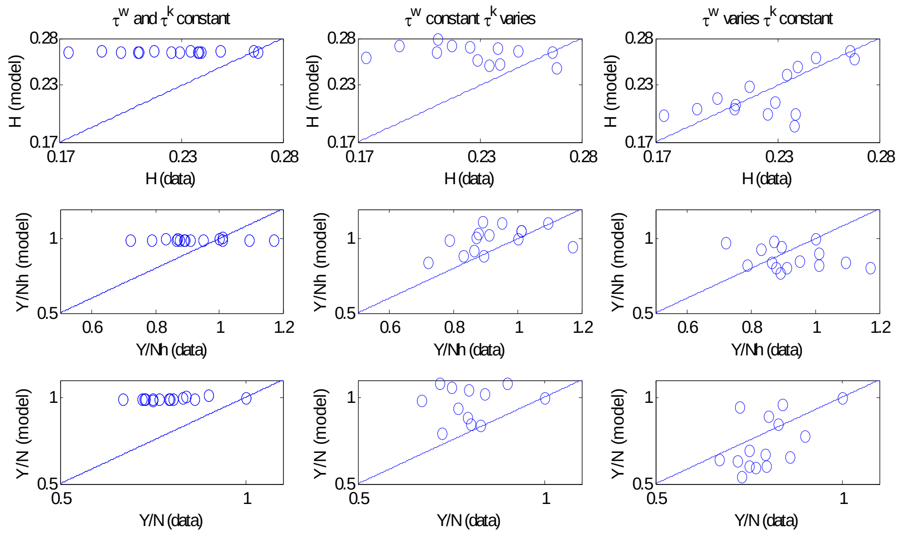

Figure 3: Decomposing the individual effects of $\widetilde{\tau}$, τ^k and population growth rates on hours worked, GDP per hour and GDP per capita. A perfect fit between the model and the data for a specific country implies a ring exactly on the 45-degree line. Left column: $\widetilde{\tau}$ and τ^k are both constant across countries, but population growth rates are set as in the benchmark calibration. Middle column: $\widetilde{\tau}$ is constant across countries, but population growth rates and τ^k are set as in the benchmark calibration. Right column: τ^k is constant, but $\widetilde{\tau}$ and the population growth rates are set as in the benchmark calibration.

contribution of each of these three factors in accounting for observed differences in GDP/capita? This is illustrated in Figure 4. Specifically, the top graph holds a and k constant so that only labor supply is varied (and once more plots the model predictions against the data). The middle graph instead holds labor supply and k constant and only varies a. The third graph, finally, holds a and labor supply constant and varies k. The figure clearly illustrates that relative productivity and capital stocks both have a low explanatory power, but that the variation in labor supply by itself quite successfully predicts the observed differences in per capita income.

Hence, for this set of countries, where inputs are measured with relatively small measurement errors, income differences are due to differences in inputs, in particular the labor supply. Differences in productivity are of less importance in the explanation of cross-country differences in GDP/capita.

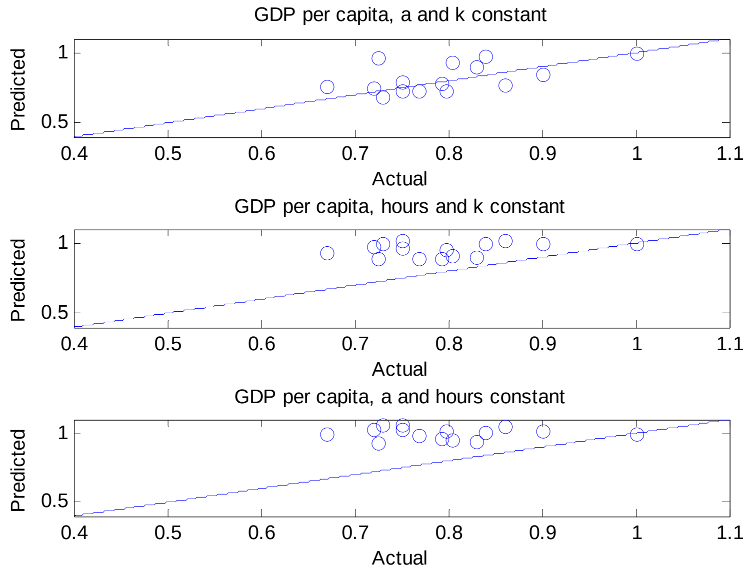

Figure 4: Evaluating to what extent differences in GDP/capita are due to differences in a, labor supply and k. Top graph: only the labor supply is varied while a and k are held constant; Middle graph: only a is varied, while labor supply and k are held constant; The third graph: only k is varied, while a and labor supply are held constant.

4.2 Capital Stocks and TFP

Up until now, comparisons have been made along three dimensions, but a relevant question is how well the model matches capital stocks and TFP levels. Unfortunately, I have not been able to find equally good and comparable OECD data on capital stocks, which are necessary for computations of total factor productivities. Comparable estimates for the capital stock are difficult first because there is more than one type of capital measure and each measure corresponds to a different analytical usage. Second, specific national assumptions underlying their compilation make their international comparability uncertain. With these caveats in mind, I use data from the Penn World Table version 7.1 to compute measures of capital stocks and TFP. Specifically, estimates of the capital stock K are computed from the perpetual inventory equation

$$K_t = I_t + (1 - \delta) K_{t-1}, \tag{37}$$

where I_t is investment. Investments are measured from PWT71 as real aggregate investment in PPP.[31] The initial capital stock is computed as $K_0 = I_0 / (g + \delta)$, where I_0 is the investment in the first year and g is the average geometric growth rate for the investment series between 1950-1970. To compute capital per person, I divide K by the size of the population.[32] Finally, I introduce capital depreciation into the model and set the length of a time period to one year, in order to make the model more comparable to the data. This implies setting $\beta = 0.96$ and $\delta = 0.25$.[33] The results are presented in figure 5.

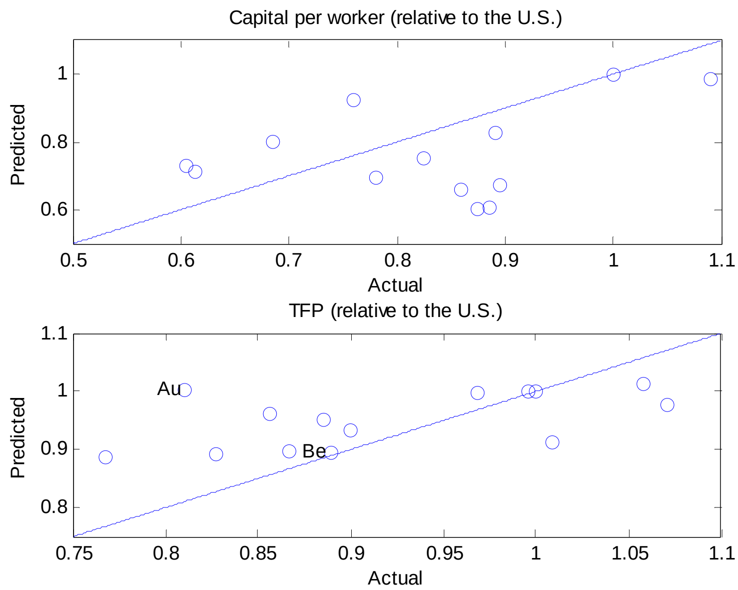

Figure 5: Actual and predicted values for capital stocks and TFP. Source: Penn World Table Version 7.1.

[31] Computed as RGDPL*POP*KI where RGDPL is real income per capita, POP is population and KI is the investment share in total income. The computation follows Caselli (2005).

[32] The values for the data are for the year 2007.

[33] It has been well documented that the results are not sensitive to choices for g and δ.

There is a positive correlation between capital stocks in the model and in the data (around 0.5), but the dispersion is somewhat higher than for hours, GDP/hour and GDP/capita. Similarly, the predictions for TFP are scattered around the 45-degree line. The model overpredicts TFP levels for Austria and Denmark (i.e., the two observations to the very left), but the correlation between the model predictions and the data is relatively high: 0.60. Note that the prediction for the TFP level in Belgium is almost perfect, i.e., it is low both in the data and in the model. Finally, according to Hall and Jones (1996), the correlation between TFP levels and GDP per *worker* is 0.94 in a data set with a large number of countries. The corresponding number of 0.85 in the model is also high (albeit slightly lower), indicating that the model is roughly consistent with the empirical estimate.

A question for future research is to try to assess whether the higher dispersion between the model and the data is due to the fact that the model is missing some important feature of the real world, or that the data is not fully comparable across countries. For instance, Pritchett (2000) argues convincingly that government investments are much less productive than private ones. Ideally, different weights should be attached to private and public investments in equation 37, but the data that is necessary for this exercise does not yet seem to exist.

The conclusion from this and the previous section is that differences in only two tax rates can go a long way in explaining the large differences in hours worked, GDP/hour, TFP, capital stocks and GDP/capita within OECD countries.

5 Comparing Other Aspects of the Model to the Data

5.1 The Marginal Product of Capital

Caselli and Feyrer (2007) argue that the marginal product of capital (MPK) is similar across countries. Because of differences in capital taxes, MPKs differ across countries in the model in this paper. Is this fact inconsistent with the empirical result? The answer is no because MPKs are not exactly the same in the data either. When the coefficient of variation of MPKs in the model is compared to that in the data (for the corresponding OECD countries), it turns out that the coefficient of variation is actually slightly lower in the model than in the data.[34] From this exercise, I conclude that the model is not inconsistent with the data when it comes to the return to capital.

5.2 Human Capital

A potential limitation of the model is that it abstracts from human capital. The reason is mainly to keep the model simple, but it would be straightforward to introduce human capital accumulation into the model. However, the above results suggest that differences in human capital may not be quantitatively important for understanding differences in labor supply, productivity and income across the countries considered. This view is also supported by Middendorf (2006) who shows that the impact of human capital on economic *growth* is fragile within the OECD.

6 Sensitivity Analysis: Endogenous Horizontal R&D

As mentioned in section 3, endogenous horizontal innovation has been shown by Zeng and Zhang (2002) and Peretto (2003) to be important for the effects of taxes on growth for economies in autarky, i.e., when there are no international technological spillovers. Specifically, taxes on labor and consumption do not have any growth effects for such a country in a Schumpeterian model. The reason is that changes in the effective labor supply then lead to changes in product proliferation that exactly offset the scale effects that were caused by changes in the labor supply.[35] This is consistent with the empirical results that show that a country's long-run growth rate does not seem to depend on its tax rates. The above model is also consistent with these empirical results, however, since no taxes will make a country grow faster or more slowly than other countries in the long run. Specifically, taxes that influence labor supply will

[34] Germany is missing in the data. The coefficient is 0.12 in the data and 0.10 in the model.

[35] Capital taxes, on the other hand, are harmful for growth also with endogenous horizontal innovation because they depress savings and capital investments.

affect the country's relative productivity, but the correlation between tax rates and growth rates is zero because all countries grow at the same global rate. In any case, in this section, the process of horizontal innovation is endogenized to completely nullify the effects on relative productivity of taxes that influence the effective labor supply.

Here, it is assumed that firms engage in R&D to come up with new intermediate products, i.e., horizontally differentiated products. As in the previous section, this type of differentiation is limited to domestic intermediate products. A successful horizontal innovator becomes a monopolist on the new product until the product is replaced by a vertical innovation. The production function for horizontal innovation is assumed to be Cobb-Douglas of the following form, i.e.,

$$Q_{t+1} = Q_t + B \left(N h_t^H\right)^{\varsigma} \left(\frac{Y}{\overline{A}}\right)^{1-\varsigma}, \tag{38}$$

where h_t^H is labor devoted to R&D for new intermediate goods and B is a constant, which is common for all countries. The production function in (38) resembles the production function for horizontal innovation in Howitt (1999), with the difference that his setting requires units of final output as inputs whereas this setting takes labor as an input. Subtracting Q from both sides of (39), and dividing through by Q_t, gives that the balanced growth rate for horizontal goods is given by

$$\frac{Q_{t+1} - Q_t}{Q_t} = B \left(\frac{N}{Q} h_t^H\right)^{\varsigma} y^{1-\varsigma}. \tag{39}$$

Recall now that h^F, k and y are all constant on a balanced growth path. Since productivity-adjusted output,y, is defined as

$$y = \left(\frac{N}{Q}\right)^{1-\alpha} \left(h^F\right)^{1-\alpha} (k)^{\alpha}, \tag{40}$$

the ratio N/Q (which was previously denoted θ) is also constant for every country on a balanced growth path, but the ratio may now differ across countries. Exactly as in the above section, the growth rate of horizontal innovation then has to equal the growth rate of the population, i.e., we must have

$$g_Q = g_L. \tag{41}$$

Using (41) in (39) and rearranging terms, y can be written as

$$y = \left(\frac{g_L - 1}{B}\right)^{\frac{1}{1-\varsigma}} \left(\frac{Q}{Nh_t^H}\right)^{\frac{\varsigma}{1-\varsigma}}. \tag{42}$$

Output is thus a function of the population growth rate, per-capita hours spent in horizontal innovation and the ratio Q/N. Each horizontal innovation produces a new intermediate product whose productivity parameter is assumed to be randomly drawn from the distribution of existing intermediate products. It is further assumed that this productivity parameter is proportional to the ratio, N/Q.[36] The value of a horizontal innovation is then

$$V_h = \frac{N}{Q} E\left(\frac{A}{\overline{\overline{A}}}\right) V. \tag{43}$$

In a long-run equilibrium, $E\left(\frac{A}{\overline{\overline{A}}}\right)$ must equal a as given by (16). The research arbitrage equation for horizontal innovation is then given by

$$(1-\alpha) A \left(\frac{\frac{N}{Q}h^F}{k}\right)^{-\alpha} = B\xi a \left(Nh_t^H\right)^{\varsigma-1} \left(\frac{Y}{\overline{\overline{A}}}\right)^{1-\varsigma} \frac{N}{Q} V. \tag{44}$$

Combining the two research arbitrage equations (29) and (44), we arrive at

$$\left(\frac{1}{h_t^H}\frac{Q}{N}y\right)^{1-\varsigma} = \frac{1}{\xi B}. \tag{45}$$

Using (42) in (45) and solving for h^H delivers per-capita hours as a function of N/Q and the population growth rate:

[36] The assumption that the productivity parameter is proportional to N/Q is made to simplify the calculations but the assumption can easily be relaxed without any significant influence on the results.

$$h^H = \underbrace{\frac{Q}{N}}_{1/\theta} (g_L - 1)\, \xi. \tag{46}$$

By combining (40) and (42) and using (26), we can solve for the ratio N/Q:

$$\frac{N}{Q} = \frac{(g_L - 1)/B}{h^F \left(\alpha^2 \beta \left(1 - \tau^K\right)/g\right)^{\frac{\alpha}{1-\alpha}}} \left[\left(\frac{1}{\xi}\right)\right]^{\frac{\varsigma}{1-\varsigma}}. \tag{47}$$

Finally, substituting (46) and (47) back into (42) delivers an expression for productivity adjusted output purely as a function of the population growth rate, i.e.,

$$y = (g_L - 1) \left(\frac{1}{\xi}\right)^{\frac{\varsigma}{1-\varsigma}} \left(\frac{1}{B}\right)^{\frac{1}{1-\varsigma}}. \tag{48}$$

Equation (48) shows that productivity adjusted output, y, does not depend on taxes when horizontal innovation is endogenous. In the previous section without endogenous horizontal innovation, taxes on labor and/or consumption would affect the labor supply in final output h^F. This would then affect the per-capita amount of time devoted to R&D – as can be seen in (30). When horizontal innovation is endogenous, this is no longer the case.

Per-capita hours of R&D are still given by (30) and taxes on labor and consumption may still influence h^F. Now, however, policies that reduce the effective labor supply also alter the incentives for product proliferation. In the long run, the ratio N/Q increases in response to a reduction in per-capita labor supply so that y remains unaltered. Note from (47) that N/Q is inversely related to h^F. Capital taxes will, however, still influence the amount of R&D undertaken.

The model with endogenous horizontal innovation features two new parameters: ς and B, and it is not obvious how to choose values for them. However, note from (48) that ς and B only show up as constants, implying that they only affect the overall level. Hence, they are of no importance for the relative levels and thus, not for the distribution of hours, GDP/hour and GDP/capita. I set $\varsigma = 0.5$ and the scale parameter B to be around one. Per capita output and GDP/hour are both still defined as in (33) and (34). The results with endogenous horizontal innovation are displayed in the left-hand column of figure 6.

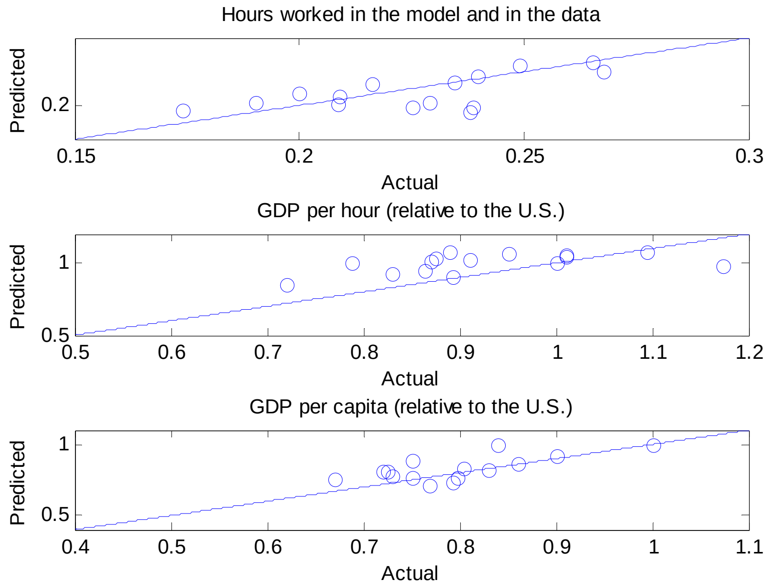

Figure 6: Actual and predicted values for hours worked, GDP per capita and GDP per hour in 15 OECD countries with endogenous horizontal innovation.

The predictions are similar to those in the previous section. Specifically, the predictions for hours are identical and the predictions for GDP/capita are actually somewhat more concentrated around the 45-degree line. The predictions for GDP/hour are similar to those in the previous section, but here they slightly overshoot the data. Therefore, this section concludes that endogenous horizontal innovation does not eliminate the result from the previous section. Instead, the main results are robust also when horizontal innovation is endogenous.

7 A Simple Tax Reform

A large literature has tried to assess the growth effects of tax reform. As pointed out in Stokey and Rebelo (1995), these estimates vary from zero to eight percent. The above model is particularly useful for addressing this quantitative question since it matches several relevant features and observations in the real world. In this section, a simple tax reform experiment is carried out in the model with endogenous horizontal innovation (where only the capital tax is of importance for the growth rate). Specifically, I analyze the effects of lowering the U.S. capital tax from the current level of 0.29 down to zero and, at the same, time adjusting the labor tax rate to keep the transfer T (19) unaltered. This requires that the combined labor/consumption tax rate, $\widetilde{\tau}$, increases from 0.2929 to 0.4779. The long-run gross global growth rate is then predicted to increase by 0.1 percentage points. This effect would be even smaller if more countries were included in the model because each country would then have a smaller impact on the global rate. The simple tax reform experiment supports the findings in Lucas (1990) and Stokey and Rebelo (1995), i.e., that the growth effects from the tax reform are small.[37]

8 Conclusions

This paper asks the quantitative question of to what extent heterogeneity in policy – or more specifically, taxes – can account for differences in inputs, productivity and output across 15 OECD countries. Inputs and productivity are measured in two different ways. As a first exercise, I use data from EU KLEMS and OECD to analyze the effect of taxes on hours worked per person, GDP/hour and GDP/capita. These three objects are well measured in the data and GDP/hour can be computed without any estimates of the capital stock as opposed to total factor productivity (TFP). This is advantageous since comparable measures of the capital stock are somewhat problematic even within the OECD. As a second exercise, I employ data from the Penn World Table to evaluate the effects on capital stocks and TFPs.

[37] The welfare effects can, of course, be large, however.

A multi-country-endogenous-growth model is employed to answer this question. In the model, all countries are connected by R&D spillovers, implying that they share the same long-run grow rate. Differences in productivity are endogenous and they depend on the incentives to carry out R&D and accumulate capital. The countries are assumed to be identical in all aspects with the only differences being that they implement different tax rates and have different population growth rates. The results show that differences in only two tax rates can go a long way in explaining the large differences in hours worked, GDP/hour, TFP and GDP/capita within OECD countries. For this set of countries where inputs are measured with relatively small measurement errors, income differences are due to differences in inputs, in particular the labor supply. Differences in productivity are of less importance in the explanation of cross-country differences in GDP/capita.

This paper takes a first step in simultaneously trying to account for the cross-country differences in hours worked per person, average productivity and GDP/capita. Thus, it sets up a fairly simple model with many countries that abstracts from potentially important features. For instance, it assumes that the only connection between the countries is technological spillovers. It would be straightforward to extend the analysis to, for instance, include trade in one or several goods.

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A Appendix

A.1 The Effect of Taxes on Hours Spent in Final Output

Recall first that the results are derived for the case where the parameters α, β, ψ all are in $(0, 1)$. Differentiating (32) respectively with respect to $\widetilde{\tau}$ and τ^k, gives

$$\frac{\partial h^F}{\partial \widetilde{\tau}} = -\frac{\left(1-\frac{g\left[1-\beta\left(1-\tau^K\right)\right]+\beta\left(1-\tau^K\right)}{\theta g\beta\left(1-\tau^K\right)}\right)}{\left(\Psi_2/g\right)^2}\cdot$$
$$\left(\psi\left(1-\alpha\right)\left(1-\widetilde{\tau}\right)\frac{g+\alpha\theta}{g}\left[1-\psi\left(1-\alpha\right)\right]+\left(1-\psi\right)\left(1-\alpha^2\beta\left(1-\tau^K\right)\right)\right)<0,$$

and

$$\frac{\partial h^F}{\partial \tau^K} = -\frac{\psi(1-\alpha)(1-\widetilde{\tau})}{(\Psi_2/g)}\left[\frac{(g-1)}{\theta g(1-\tau^K)}+\frac{g\left[1-\beta\left(1-\tau^K\right)\right]+\beta\left(1-\tau^K\right)}{\left(1-\tau^K\right)^2}+\frac{\left(1-\frac{g-(g-1)\beta\left(1-\tau^K\right)}{\theta g\beta\left(1-\tau^K\right)}\right)(1-\psi)\alpha^2\beta}{(\Psi_2/g)}\right] < 0.$$

Note that $\frac{g\left[1-\beta\left(1-\tau^K\right)\right]+\beta\left(1-\tau^K\right)}{\theta g\beta\left(1-\tau^K\right)}<1$, because otherwise, h^R is negative in (30).

A.2 The Effect of Taxes on Research Hours

Similarly, differentiating (31) respectively with respect to $\widetilde{\tau}$ and τ^k, gives

$$\frac{\partial h^R}{\partial \widetilde{\tau}} = -\frac{\alpha\theta\psi(1-\alpha)}{\Psi_2}\left(\frac{(1-\psi)\left(1-\alpha^2\beta\left(1-\tau^k\right)\right)g}{\Psi_2}\right)$$
$$-\frac{g\left[1-\beta\left(1-\tau^k\right)\right]+\beta\left(1-\tau^k\right)}{\theta g\beta\left(1-\tau^k\right)}\frac{1}{\Psi_2}\left(\psi\left(1-\alpha\right)g+\frac{\Psi_1}{\Psi_2}\right)<0,$$

and

$$\frac{\partial h^R}{\partial \tau^k} = -\frac{1}{\Psi_2}\left[\left(1-\psi\right)\alpha^2\beta g h^R+\frac{g(1-\beta)+\beta}{\theta g\beta\left(1-\tau^k\right)}\Psi_1+\right.$$
$$\left.\frac{g\left[1-\beta\left(1-\tau^k\right)\right]+\beta\left(1-\tau^k\right)}{\theta g\beta\left(1-\tau^k\right)}\left(\frac{\Psi_1\theta g\beta}{(1-\tau^K)}+\left(1-\psi\right)\left(\alpha^2\beta\left(1-\tau^k\right)\right)g\right)\right] < 0.$$

A.3 The Effect of Taxes on GDP/hour

Differentiating (34) with respect to $\widetilde{\tau}$ delivers that GDP/capita is strictly decreasing in $\widetilde{\tau}$, i.e, that

$$\frac{\partial GDP/hour}{\partial \widetilde{\tau}} = \frac{Y}{N(h^F+h^R)}\left(\frac{\partial h^R}{\partial \widetilde{\tau}}\left[\frac{1}{h^R}\frac{g-1}{1-(1-\theta h^R)g}-\frac{1}{h^F+h^R}\right]+\frac{\partial h^F}{\partial \widetilde{\tau}}\left[\frac{1}{h^F}-\frac{1}{h^F+h^R}\right]\right)<0.$$

The above expression is negative because the partial derivatives are both negative and the expressions in square brackets are both positive.

Similarly, differentiating (34) with respect to τ^K delivers that GDP/capita is strictly decreasing in τ^k, i.e., we get

$$\frac{\partial GDP/hour}{\partial \tau^K} = \frac{Y}{N(h^F+h^R)}\left(\frac{\partial h^R}{\partial \tau^k}\left[\frac{1}{h^R}\frac{g-1}{1-(1-\theta h^R)g}-\frac{1}{h^F+h^R}\right]+\frac{\partial h^F}{\partial \tau^k}\left[\frac{1}{h^F}-\frac{1}{h^F+h^R}\right]-\frac{1}{1-\tau^K}\frac{\alpha}{1-\alpha}\right)$$

Note once more that the partial derivatives are both negative and the expressions in square brackets are positive. In addition, the last term in parenthesis is positive with a minus sign in front of it, which also contributes to the negative effect.

B Time trends in GDP/capita and GDP/hour

Figure 7 shows the evolution of GDP/capita and GDP/hour from 1980-2007 for the countries considered. The figure shows that even though there are some individual movements between the countries, they basically follow parallel growth paths. This is consistent with the assumption that the countries have reached their steady state and that they grow at a common world rate.[38]

[38] The figure thus verifies the evidence in Evans (1996) which shows that the dispersion of GDP per capita across advanced countries shows no tendency to rise over time.

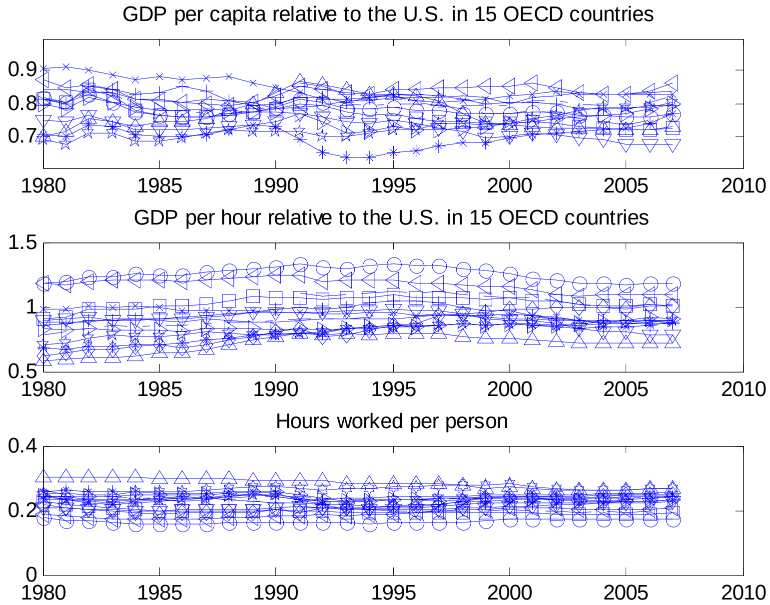

Figure 7: Top graph: GDP per capita relative to the U.S. from 1980 to 2007. Bottom graph: GDP per hour relative to the U.S. for the same time period.

C Estimating Average Effective Tax Rates

The approach developed by Mendoza et al. (1994), is used to estimate the current tax rates on labor τ^w, consumption τ^c and capital τ^k. The idea is to relate realized tax rates directly to the relevant macroeconomic variables in the National Accounts. The resulting estimates are known as average effective tax rates (AETR), "implicit rates" or "tax ratios", and are consistent with the concept of aggregate tax rates at the national level and the representative agent framework. This method has the advantage that it takes into account the net effect of existing rules regarding credits, exemptions and deductions. It also incorporates the effects of taxes not filed with individual income tax returns. The disadvantage is that it does not use any information on statutory tax rates and income distribution per tax rate. The tax revenue data is from the OECD Revenue Statistics database, which contains information on tax revenues as reported by member countries. Estimates of the value of the associated tax bases **are** from the OECD National Accounts data base.

Table 3: Variable names and symbols used

Revenue Statistics:
1100 = Taxes on income, profit and capital gains of individuals or households
2000 = Total social security contributions
2200 = Social security contributions paid by employers
2300 = Social security contributions paid by self-employed
3000 = Taxes on payroll and workforce
4000 = Taxes on property
4100 = Recurrent taxes in immovable property
4400 = Taxes on financial and capital transactions
5110 = General taxes on goods and services
5121 = Excise taxes
National Accounts:
CP = Household final consumption expenditure
CG = Government final consumption expenditure
OS = Net operating surplus of the overall economy
OSPUE = Households' unincorporated operating surplus
PEI = Households' property income
S = Household consumption expenditures on services
W = Wages and salaries

Mendoza et al. (1994) exclude government wage consumption from the consumption tax base on the grounds that they are not subject to indirect tax. The AETR on consumption goods is then given by

$$\tau^c = \left[\frac{5110 + 5121}{CP + CG - 5110 - 5121}\right] \times 100.$$

Indirect taxes are deducted in the denominator to express the indirect tax rate as a percentage of the pre-tax price.

The approach to calculate AETRs on labor and capital is to first calculate AETR on total household income, τ^i, as given by (49)

$$\tau^i = \left[\frac{1100}{OSPUE + PEI + W}\right] \times 100. \tag{49}$$

Taxes on labor and capital are then, respectively, calculated from equations (50) and (51):

$$\tau^w = \left[\frac{\tau^i W + 2000 + 3000}{W + 2200} \right] \times 100, \tag{50}$$

and

$$\tau^k = \frac{[\tau^i (OSPUE + PEI - WSE - 2300) + 1200 + 4100 + 4400]}{OS - WSE - 2300}, \tag{51}$$

where WSE is the wages for the self-employed. Capital taxes are computed using the revised method presented in Carey and Tchilinguirian (2000). The main difference is that the method in Mendoza et al. (1994) assumes that all income for the self-employed is a return to capital, whereas Carey and Tchilinguirian compute an imputed "wage bill" for the self-employed in order to reduce the underestimation of the labor income of the self-employed.

D Alternative Parameter Values

Since, the parameter ϕ cannot be inferred from the data, it was set to be 0.55. In this section, a lower and a higher value are considered. The results are displayed in Figure 8.

As can be seen, ϕ mainly affects GDP/hour. The correlation between the model predictions and the data for GDP/hour is lower for $\phi = 0.45$, whereas it is still high for $\phi = 0.65$.

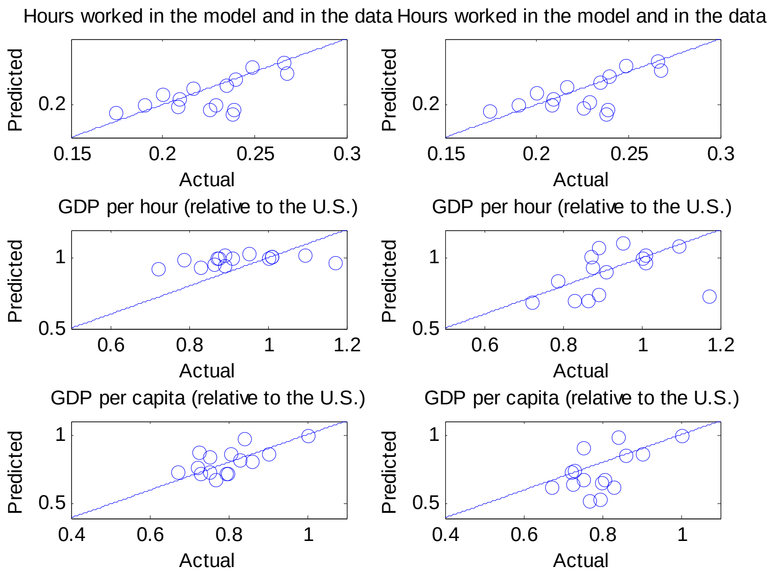

Figure 8: Actual and predicted values for hours worked, GDP per capita and GDP per hour in 15 OECD countries. Left column: $\phi = 0.45$ and right column: $\phi = 0.65$.