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Submission Number: PET11-11-00311

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I am grateful for helpful comments to Allan Drazen, Pablo D''Erasmo, Boragan Aruoba and John Shea. All errors are mine.
Submitted: March 18, 2011.

Higher Education in a Heterogenous-Agent Economy: Revisiting the Transatlantic Differences*

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March 4th, 2011

Preliminary and Incomplete

Abstract

Structural differences between the U.S. and the Nordic European countries' higher education systems are well documented. In this paper, I propose a heterogenous-agent OLG model with both public and private education options available in the choice set of agents, presence of economy-wide complementarities, limited spillover of public education when private education is chosen, and distortionary taxes for public education financing. I show that the model can generate the U-shaped pattern of per-capita output over public-education-expenditure share in data, and for a given tax rate difference of approximately 7%, it can deliver many of the empirical differences between the U.S. and the Nordic European economies. I also show that in the presence of minor adjustment costs, the targeted tax rates can gain political support.

JEL Classification: I2, P16, E24

Keywords: Human capital, public education, inequality, multiple equilibria

*I am grateful for helpful comments to Allan Drazen, Pablo D'Erasmo, Borağan Aruoba and John Shea. All errors are mine.

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1 Introduction

Higher education plays an important role in a modern economy by being a fundamental determinant of economic growth and income inequality through the human capital channel.[1] While the role of higher education is well-acknowledged, ideal and sustainable mechanism-design for education systems has been a controversial issue among researchers.[2]

Lack of consensus about ideal higher education systems is present among policy-makers, as well. Sources of financing and the public versus private education choice are two of the most central and controversial issues regarding the education system choices, and countries show substantial disparities in these dimensions. Figure 1 exemplifies this point in one of the dimensions: It demonstrates tertiary public education average tuition fees across some of the OECD countries. Noticeably, the average tuition fee in the U.S. lies above the remaining developed countries, and the discrepancy is much more evident when the comparison is between the U.S. and the Northern European "welfare" countries, (Denmark, Finland, Iceland, Norway and Sweden) which have zero tuition fees. Since Figure 1 accounts only for the public institutions, one can examine both public and private higher education fees, as well as some other fundamental indicators of the countries of interest in Table 1. Clearly, as shown in the first two columns average tuition in the U.S. is not only higher for public institutions but also for private institutions. Average private tuition for the Nordic countries is only one-tenth of the U.S. fee. The fourth column in Table 1 shows that while no less than 89% of tertiary type-A[3] students are enrolled in public institutions in Scandinavian countries, approximately two-thirds of students in the U.S. attend public type-A programmes. Using these weights, as well as the data on scholarship opportunities, I derive average tuition fees across countries and illustrate the results in the third and the fourth columns.[4] My calculations suggest that while average Scandinavian tuition fees are negligible compared to their per-capita income levels, these fees account for approximately 22% of the U.S. per-capita income.[5] Also, as demonstrated in the 6th and 7th columns, the net

[1]For detailed literature review on the role of human capital in macroeconomics, see Romer(1986), Lucas (1988), Bénabou (1996), and Glomm and Ravikumar (1992) among others.

[2]While there is a reasonable degree of consensus in the literature that public education alleviates income inequality in the long-run (e.g. Glomm and Ravikumar, 2003; Bénabou, 2005), differing results have been documented for output growth. For instance, whereas Glomm and Ravikumar (2003) claim private education fuels output growth more than public education, many claim otherwise (Bénabou, 2000, 2002, 2005; Zhang, 2005).

[3]According to the OECD definition, tertiary-type A programmes (ISCED 5A) are largely theory-based and are designed to provide sufficient qualifications for entry to advanced research programmes and professions with high skill requirements, such as medicine, dentistry or architecture, and typically last four or more years.

[4]Due to lack of some data including scholarship data for Norway, and average private tuition for Denmark, I estimate the average tuition fees in a most conservative way not to underestimate Nordic average tuition costs. Details of calculations are available upon request.

[5]One could suspect this discrepancy being as a result of implicit costs. Global Higher Education Rankings 2010 report suggests that higher private education costs of the U.S. result holds even after controlling for all implicit costs, including cost of living, out-of-pocket expenses, tax-rate differentials, fellowship opportunities, etc.

entry rates to higher education institutions and proportions of the population holding higher education degrees for the countries of interest are comparable.[6]

Another way to document the presence of structural disparities in higher education systems across countries is to focus on aggregate higher education expenditure and its composition. As illustrated in Figure 2, while higher education expenditures in Scandinavian countries are only slightly over the OECD average, the U.S. has the largest higher education expenditure per student. A deeper analysis of higher education expenditures of the U.S. and the Nordic countries is shown in Table 2. The first column shows that higher education expenditure per student in the U.S. is almost double that of the Nordic average, yet decomposing the expenditures reveals that public higher education expenditure in the U.S. is still lower than those of Nordic countries, except for Iceland. Further, whereas the ratio of public higher education expenditure to total higher education expenditure is no less than 87.5% for the Scandinavian countries, it is only about one-third for the U.S. One final structural difference concerns the return on education. The increase in wages as a result of holding a higher education degree in the U.S is double the increase of the Nordic average, which can possibly be due to the higher variation in educational performance scores in the U.S., as argued by Nickell (2004) and exemplified in Figure 3. Although higher incremental increase of wages and educational costs of the U.S. could arise from superior *average* quality of the U.S. higher institutions, empirical evidence does not support this hypothesis. In fact, if OECD PISA level 6 scores, which aim to project students' educational performances in earlier stages of advanced education, can be indicators of higher education quality, the U.S. clearly does not have significantly better results on average when compared to the Nordic countries, as illustrated in Figure 4. Instead, more unequal wages in the U.S. are probably due to more unequal educational attendance, thus formation of human capital. An anecdotal evidence supporting this view is by Barry McGaw, (Director of Education for the OECD) who states in a speech that "...the very best schools in the U.S. are extraordinary ... but the big concern in the U.S. is the *diversity* of quality of institutions...".

Another important Transatlantic difference is on taxation. The continental European countries, especially Northern ones are known to have considerably more progressive and higher income tax structure than that of the U.S.[7]. Although tax schemes are highly complicated, which makes comparison challenging, a simpler measure such as taxes on income and profits as a percentage of countries' respective GDPs can be employed to show that Scandinavian gov-

[6]Although population with higher education in the U.S. is slightly above the Nordic average, the reason is mainly due to the inclusion of the older population: Whereas the ratio of older population (55-64) who hold higher education degrees in the U.S. is very close to the younger population (25-34), this is not the case for Scandinavia where the difference is higher in favor of younger population, which suggests one would expect even closer rates in the short-run.

[7]For a detailed discussion on taxation and redistribution on countries of interest, see Alesina and Glaeser (2004).

ernments levy significantly higher income taxes on *average*, as illustrated in Table 3. Also, if all taxes are to be considered for comparison, total tax revenues of countries of interest can be shown to differ drastically as well, as shown in Table 4. While these governments use tax revenues on many accounts, at least some fraction is known to be utilized in the financing of public education depending on the necessary level to be provided.

A final remark on the countries of interest is that both the U.S. and the Nordic countries are known to be well-established democracies with very high performances in electoral processes and pluralism.[8] Therefore, it must be that the different higher educational systems and tax schemes receive consent from majority of the electorates of their respective countries.

In the light of these observations, a natural question that can be raised is: "Why do we observe these radical discrepancies between the U.S. and the Scandinavian countries' public versus private higher education choice and composition given that they are all well-established democracies with comparable income levels? " Also on the normative side, another question that can emerge is: "Is it possible to come up with welfare-improving policy recommendations that are *politically sustainable*, i.e. that can survive under democratic elections?"

This paper concentrates on the structural differences between the U.S. and the Nordic European countries' education systems and tries to address the above questions. I propose a heterogenous-agent overlapping generations (OLG) model with both public and private education options available in the choice set of agents. I show that in the presence of economy-wide complementarities, limited benefits of public education when private education is chosen, and distortionary taxes for public education financing, the model can deliver many of the empirical differences fairly well for given taxes. In particular, with an exogenous tax rate difference of approximately 7%, the model can match target countries' GDP (PPP) per capita ratios and public-higher-education-expenditure ratios with a very high precision. Further, the model can deliver higher total-higher-education-expenditure-to-GDP, higher labor and lower public school attendance ratios, as well as more unequal distributions of macro variables for the U.S. when compared to the Nordic countries. Next, I show that in the presence of even minor adjustment costs, the targeted tax rates can gain political support. Also, some other insights that the model delivers can be summarized as follows:

1. In the presence of distortionary taxes for public education financing, relying purely on public or purely on private education can yield higher average output, consumption, human capital, and education than taking the "middle road", i.e. using both at the same time by some significant fraction of population. The intuition behind this result is that, even when the returns to public and private education are equal, positive complementarity effect

[8] See "The Economist Intelligence Unit's Index of Democracy", 2008 and "Freedom in the World", Freedom House, 2008, among others.

fueled by extra higher education attainment of the poor as a result of attending public schools are offset by the "disincentivizing" role of distortionary taxes and public education level on private education, i.e. higher provision of public education reducing the incentive of individuals to choose higher levels of private education spending for their children.

2. Due to the disincentivizing effect of public education on the extensive margin of the private education, output, education, labor and human capital inequalities initially increase as tax rate goes up, and only after a threshold they start to decrease. In other words, taxes and redistribution in the form of public education does not monotonically reduce inequality in the presence of both public and private education, contrary to what is claimed by studies in the literature. This feature of the model captures higher inequality of income and education in the U.S. at modest levels of public education expenditure.

3. Data suggests that developed countries' GDP (PPP) per-capita display a U-shaped pattern over the public education expenditure shares, as well as tax rates. The model with limited public education spillover succeeds to mimic the U-shaped stationary-equilibria values for per-capita income over tax rates and public education shares, as well.

The rest of the paper is organized as follows: In section 2, I discuss about the related literature, in section 3, I describe the model environment, in section 4, I report and discuss about my findings, and section 5 concludes.

2 Related Literature

Previous studies in the literature on the role and composition of education and Transatlantic differences lack rigorous conclusions both on the source of the aforementioned discrepancies, and the resultant macroeconomic implications. Very few papers attempt to explain the aforementioned discrepancies in education using methods employed by neoclassical economic theory. Bénabou (2000), being the exception, investigates the role of progressivity of taxes and redistribution on education in a heterogenous-agent economy, and shows that two distinct equilibria can emerge depending on whether efficiency-enhancing effect or redistributive one dominates. He emphasizes solely the role of imperfections in democracies while explaining how different economies could stay inertial at these equilibria. However, he works with a very stylized model, makes many restrictive assumptions on the parameter space to derive closed-form solutions, and he does not distinguish between public versus private education. Also, he does not rigorously investigate why and how possible democratic imperfections can emerge.

Soares (2006) also analyzes the role and determination of education in a dynamic general equilibrium model under democracy, yet he does not focus on the aforementioned discrepancies between the countries of interest. He introduces heterogeneity only by age-cohorts in an overlapping generation model. The orthodox point of view in the literature is that the most fundamental source of heterogeneity with regards to education is innate productivity (which in turn affects human capital, labor, income, wealth and education levels) (e.g. Bénabou, 2000, 2005; Zhang, 2005), and I also believe that it is imperative to incorporate heterogeneity in this dimension while studying the role of education. Finally, Zhang (2005) also studies the role of education with the presence of both physical and human capital, and reaches similar qualitative conclusions as in Bénabou (2000), yet he does not introduce public education in his model, either.

A related growing branch of literature is on why European countries have more pronounced redistributive policies than the U.S. and what the implications of different policies are. In an earlier attempt, Lindbeck (1995) argues that habits and social norms influence economic incentives, which in turn shape habits and social norms. As a result of this feedback mechanism multiple equilibria can emerge. Saint-Paul (2001) focuses on economic explanations and formally shows that contrary to the general prediction that higher inequality induces more redistributive policies, if a large fraction of population is concentrated at the lower-tail of the distribution, redistribution may fall and inequality may rise at the same time. Similar to Saint-Paul's (2001) qualitative conclusions, Hassler *et al* (2003) argue that expectations of high future redistribution can lead to lower investments today, which in turn increases future demand for redistribution, and this feedback mechanism allows for the presence of multiple equilibria.

Alesina and Glaeser (2004) make an excellent review and group potential sources of present differences into economic, political and behavioral fundamentals. Economic explanations rely on differences in variance and skewness of pre-tax income, social costs of taxation, and income mobility prospect of the median-voter. They claim that overall, empirical evidence does not support economic explanations strongly since pre-tax and transfer income in the United States has both higher variance and a more skewed distribution; deadweight losses from taxation are not proven to be lower in Europe; and European Union integration has not changed the degree of redistribution significantly.[9]

Political explanations focus on institutions that prevent minorities of any sort from gaining political power or that strictly protect individuals' private property. Examples of such institutions can be the lack of representative democracy in the U.S. which could promote bargaining power for small groups with common interests, (e.g. absence of a socialist party which are represented strongly in many of the European countries), and the U.S. Supreme Courts' pro-

[9] Alesina and Glaeser (2004) also show that prospects of moving up in the income distribution may be higher for the U.S. middle-class households, which could incentivize them to vote for lower and less progressive redistributive policies, yet despite the presence of this controversial fact, they believe economic explanations are not likely roots for divergent multiple equilibria.

private-property attitude (as in the rejection of federal income tax in 1894). Authors argue that political explanations have at least some legitimacy in explaining the observed structural differences. For instance, Alesina *et al* (2002) claim that empirically racial discord hinders redistribution significantly. For the U.S. case, they claim that due to racial animosity, many voters find it unappealing to vote for pronounced redistribution to the poor, who are proportionately black. Electorates want to have control over their charitable donations, and direct them as they please.

Behavioral explanations focus on the perception of fairness of the market and the role of luck and effort in determination of economic outcomes. Alesina and Angeletos (2005) argue that if the common perception in an economy is that luck is strongly decisive in economic outcomes, agents will be highly unlikely to be motivated to put in high effort. In equilibrium, due to limited effort, luck will be very influential, and initial beliefs that luck is decisive on final outcomes will be verified. At the same time, in order to insure themselves against unlucky future scenarios, agents will favor redistributive policies over *laissez-faire* ones. In contrast, if agents perceive the market to be fair and the role of luck to be minimal, they will be more motivated to put in high effort, which in turn reduces the decisiveness of luck in equilibrium. Under this scenario, *laissez-faire* policies are favored over pronounced redistributive policies due to foreseeable future and less need for insurance. Authors show that 54% of Americans believe effort determines final outcome whereas only 29% of the population in Europe is in agreement with this belief. They document a significant uni-directional causality from perception of high decisiveness of luck to social spending per-capita across countries, and establish a model based on these preliminaries that could generate multiple equilibria. Bénabou and Tirole (2006) also set up a model with beliefs that are verified in equilibrium, yet using the "need" to believe in a just world and "cognitive dissonance" as the necessary elements of their model, which can generate multiple equilibria based on behavioral fundamentals. Although these papers shed light to Transatlantic differences to a great extent by formalizing behavioral explanations, they both rely on unorthodox elements to the neoclassical economic theory, and the models are not very suitable for policy analyses.

So far, determination and implications of an education system in a heterogenous-agent economy where both public and private education options exist have not been investigated. Further, welfare anayses of individuals have often been neglected. This paper intends to fill this gap in the literature by combining the features of a standard heterogenous-agent general equilibrium model with the elements proposed in the redistributive policy literature that are put forward to generate multiple politically-sustainable equilibria. I also show that when studying the role and determination of education, the presence of both public and private education options in agents' choice set is critical since pure redistribution of a single education type (e.g. as in

Bénabou, 2000) fails to account for the crucial disincentivizing role of public education, which causes overestimation of the benefits of public education and generates misleading predictions on the behaviors of important macroeconomic variables, e.g. average per-capita variables, and inequality. Further, it is important to acknowledge that the form of public education in the Scandinavian countries are mostly predominant attendance to public schools, as opposed to subsidies for private education, which also supports the view that a more realistic representation of reality also requires the distinction between the two types of education systems. This paper, at least partially, sheds some light on these grounds, as well.

3 Model

Before introducing the hybrid model where both public and private education options are available, first I examine two polar cases, one with only private education and one with only public education. Next, by combining the two models, and incorporating an additional element of public education spillover, the details of which will be discussed shortly, I establish the hybrid model where both public and private education choices are viable.

The models I describe in the following subsections are heterogenous-agent overlapping generations (OLG) models with two cohorts, young and middle-aged, both with the same measure (normalized to 1), and no population growth. The young are born with an in-born exogenous cognitive capacity. This stochastic capacity, as well as education bequests from his parent (if any) or the present public education level, economy-wide human capital, and the human capital of his parent determine his human capital, which he uses next period when middle-aged. The young do not optimize, and only abide by the law of motion for human capital.[10] The middle-aged decides how much to work, consume, and bequest for the offspring's education due to altruism. Further, the middle-aged also vote on the level of a distortionary income tax, which is the only instrument to finance public education. As a result of democratic elections, the most preferred tax rate of the majority emerges as the only income tax rate in the economy, determining the level of public education together with the level and distribution of human capital and labor supply.

The primary focus of the paper is to study the properties of the steady-state, therefore the model assumes there is no aggregate shock hitting the economy, which in turn implies that in the economy will stay at the stationary equilibrium at all times where all aggregate variables and the distributional properties of variables of interest are constant at their long-run values.

[10] Although this is somewhat restrictive of an assumption, it would significantly help to keep computational solution of the model. In the standard case, the young does not consume at all, or in other words, his consumption is normalized to zero. This can be relaxed with ease as long as the young does not solve an optimization problem.

3.1 Pure Private Education Model

The middle-aged are the only decision-making cohort in the economy. Middle-aged agent i at time t solves:

$$V_t^i(h_t^i, \xi_t^i; \overline{H}) = \max_{\{c_t^i, e_t^i, l_t^i\}} \left\{ u(c_t^i) + v(1 - l_t^i) + \rho \mathrm{E}_t V_{t+1}^i(h_{t+1}^i, \xi_{t+1}^i; \overline{H}) \right\} \tag{1}$$

subject to

$$c_t^i = \Theta {l_t^i}^{1-\lambda} {h_t^i}^{\lambda} - e_t^i \tag{2}$$

and

$$e_t^i \geq 0 \tag{3}$$

for given parameters, and aggregate human capital $\overline{H}$, where c denotes consumption, l denotes labor, h denotes individual-specific human capital, e denotes the private education bequest, ρ denotes altruistic discount rate, Θ denotes the constant technological productivity, and ξ denotes the in-born cognitive competence measure (e.g. IQ level) of the agent's offspring. Education bequest decision happens *after* middle-aged agent observes his child's cognitive capacity. In other words, ξ_t denotes the innate cognitive capacity of the young agent at time t, and not the middle-aged. Further, human capital evolves according to

$$h_{t+1}^i = \xi_t^i (e_t^i)^{\varepsilon} ((1 - l_t^i) h_t^i)^{(1-\varepsilon)\gamma} \overline{H}^{(1-\varepsilon)(1-\gamma)} \tag{4}$$

where

$$\overline{H} = \int_0^1 h_t^i di \tag{5}$$

so that there are complementarities[11] and limited transmission of skills across generations.[12] Also, innate cognitive capacity follows:

$$\log(\xi^i) \sim N(\mu_\xi, \sigma_\xi^2) \tag{6}$$

3.2 Pure Public Education Model

The set-up is similar to the pure private education model, except for education choice and its financing: There is a single public education level determined in the economy by democratic elections, and financed by a single income tax.[13] The middle-aged agent i solves a two-stage problem. First, he votes sincerely for the tax rate τ_t^i that maximizes his welfare:[14]

$$V_t^i(h_t^i, \xi_t^i; \overline{H_{\tau_t^i}}, \overline{E_{\tau_t^i}}) = \max_{\{\tau_t^i \in [0,1]\}} \left\{ u(c_t^{i^*}) + v(1 - l_t^{i^*}) + \rho \mathrm{E}_t V_{t+1}^i(h_{t+1}^i, \xi_{t+1}^i; \overline{H_{\tau_{t+1}^i}}, \overline{E_{\tau_{t+1}^i}}) \right\} \tag{7}$$

where $c_t^{i^*}$ and $l_t^{i^*}$ are the optimal decision rules derived from the second stage which are the *argmax* to the next optimization problem, and $\overline{H_{\tau_t^i}}$, and $\overline{E_{\tau_t^i}}$ are the resultant aggregate human capital and public education levels determined jointly in the two stages when τ_t^i is in act. The second stage optimization problem can be described as follows:

$$V_t^i(h_t^i, \xi_t^i; \overline{H_{\tau_t}}, \overline{E_{\tau_t}}) = \max_{\{c_t^i, l_t^i\}} \left\{ u(c_t^i) + v(1 - l_t^i) + \rho \mathrm{E}_t V_{t+1}^i(h_{t+1}^i, \xi_{t+1}^i; \overline{H_{\tau_{t+1}}}, \overline{E_{\tau_{t+1}}}) \right\} \tag{8}$$

subject to

$$h_{t+1}^i = \xi_t^i (\overline{E_{\tau_t}})^\varepsilon ((1 - l_t^i) h_t^i)^{(1-\varepsilon)\gamma} \overline{H_{\tau_t}}^{(1-\varepsilon)(1-\gamma)} \tag{9}$$

[11] In the literature, some authors (e.g. Bénabou, 2005) introduce complementarities in the economy by incorporating aggregate human capital as a factor of production in output production technology. I believe, incorporating complementarities in individual-specific human capital's law of motion, as done by Zhang (2005) is a more reasonable approach, and modeling it as Bénabou (2005) does not change results qualitatively.

[12] The skill-passing of human capital across generations is an orthodox approach in the literature. In fact, Schuetz *et al* (2005) empirically verify the presence of skill-passing through generations across countries at different magnitudes. For a detailed discussion on the family background effect on educational performance and list of a number of studies verifying the significant presence of causality, see Hanushek and Woesmann (2010).

[13] I model public education in a non-rival and non-excludable fashion. In reality, public education is known to be at least partially rival, i.e. number of students attending public education is known to matter. Also, for both U.S. and Scandinavian countries, only about 40% of the students attend to higher education, which implies there is excludability present as well, although in similar degrees for countries of interest. These assumptions are aimed to keep models simple and tractable enough, and further research which relax these assumptions would be enlightening.

[14] Given that there are no aggregate shocks in the economy, agent i knows with certainty what equilibrium aggregate variables, and thus what his welfare is going to be when his vote τ_t^i is decisive, as well as at other tax rates, but he cannot vote strategically. In other words, the model assumes rationality, perfect foresight and non-strategic voting. Also, he assumes that if his preferred tax rate is decisive today, it will also be decisive tomorrow due to the fact that the economy stay inertial at the steady state.

where $\overline{H_{\tau_t}}$, and $\overline{E_{\tau_t}}$ are economy's human aggregate capital and public education level after economy's tax rate τ_t is chosen in elections by majority rule. The government runs a balanced budget, which accordingly requires

$$\overline{E_{\tau_t}} = \int_0^1 \tau_t(\Theta l_t^{i^{1-\lambda}} h_t^{i^{\lambda}})di \tag{10}$$

In-born productivity shocks are distributed identical to the former model, as described in equation (6).

3.3 Hybrid Education Model

The hybrid education model is the mixture of the two polar cases, with an additional *public education spillover* component. At the beginning of each period, elections are held and the economy's tax rate, and implicitly the public education level is determined by majority rule, as in the pure public education scenario. After this stage, for the given level of tax and public education level, middle-aged agent i decides whether to choose the current public education or private education and its level for his child. Public education is provided in a non-rival and non-excludable way, yet offered in a take-it-or-leave-it fashion at some degree: Those who choose private education, regardless of the level of their choice, cannot fully enjoy public education benefits and incur an opportunity cost of forgoing some portion of the public education level. Private education is not free, however they provide the opportunity to pick any level of education, only at its respective cost.

Formally, at the first stage, middle-aged agent i at time t solves:

$$V_t^i(h_t^i, \xi_t^i; \overline{H_{\tau_t^i}}, \overline{E_{\tau_t^i}}) = \max_{\{\tau_t^i \in [0,1]\}} \left\{ u(c_t^{i^*}) + v(1 - l_t^{i^*}) + \rho \mathrm{E}_t V_{t+1}^i(h_{t+1}^i, \xi_{t+1}^i; \overline{H_{\tau_{t+1}^i}}, \overline{E_{\tau_{t+1}^i}}) \right\} \tag{11}$$

for given $c_t^{i^*}, l_t^{i^*}, e_t^{i^*}, \overline{H_{\tau_t^i}}$, and $\overline{E_{\tau_t^i}}$.

Next, once the economy's tax rate emerges after elections, agent i takes tax rate τ_t, the level of public education $\overline{E_{\tau_t}}$, and aggregate human capital $\overline{H_{\tau_t}}$ as given and compares his welfare under the level of public education against any possible positive private education bequests. Specifically, he solves:

$$V_t^i(h_t^i, \xi_t^i; \overline{H_{\tau_t}}, \overline{E_{\tau_t}}) = \max_{\{c_t^i, l_t^i, e_t^i\}} \left\{ u(c_t^i) + v(1 - l_t^i) + \rho \mathrm{E}_t V_{t+1}^i(h_{t+1}^i, \xi_{t+1}^i; \overline{H_{\tau_{t+1}}}, \overline{E_{\tau_{t+1}}}) \right\} \tag{12}$$

subject to

$$c_t^i = (1 - \tau_t)\Theta l_t^{i^{1-\lambda}} h_t^{i^{\lambda}} - e_t^i \tag{13}$$

$$e_t^i \geq 0 \tag{14}$$

$$h_{t+1}^i = \begin{cases} \xi_t^i(\overline{E_{\tau_t}})^{\varepsilon}((1-l_t^i)h_t^i))^{(1-\varepsilon)\gamma}\overline{H_{\tau_t}}^{(1-\varepsilon)(1-\gamma)}\} & e_t^i = 0 \\ \xi_t^i(e_t^i + \nu\overline{E_{\tau_t}})^{\varepsilon}((1-l_t^i)h_t^i)^{(1-\varepsilon)\gamma}\overline{H_{\tau_t}}^{(1-\varepsilon)(1-\gamma)} & e_t^i > 0 \end{cases} \tag{15}$$

$$\overline{H_{\tau_t}} = \int_0^1 h_t^i di \tag{16}$$

$$\overline{E_{\tau_t}} = \int_0^1 \tau_t(\Theta {l_t^i}^{1-\lambda} {h_t^i}^{\lambda})di \tag{17}$$

$$\log(\xi^i) \sim N(\mu_\xi, \sigma_\xi^2) \tag{18}$$

where ν in equation (15) denotes the fraction of public education benefit of the private school students, or the *public education spillover*.[15] In other words, if ν takes a non-zero value, students who attend private education can still enjoy a fraction of the present public education level.

After solving this maximization problem, the middle-aged agent chooses the level of private education, and the economy moves to the next period. If the agent chooses public education, his private education spending would be zero.

Due to the absence of studies or data on the public education spillover, in the next section I report results with three alternative parameter values of ν : $0, 0.5$ and 1. The model with $\nu = 0$, coined as the hybrid model with no public education spillover, can be considered as an environment where there are only two major types of higher education institutions, and students can attend only one type of them at a time, i.e. public education is offered in a perfectly take-it-or-leave-it fashion. The model with $\nu = 1$, tagged as the hybrid model with maximum public education spillover, can be thought as an environment where there is only the public higher education institute type, and any student who wants to get higher education has to attend public schools. In addition to the public education, those who want to pursue further education can choose to attend private education of any kind, e.g. private tutoring, certificate programs, etc., have to incur the cost, but do not have to forgo public school benefits. This specification is intended to capture Nordic countries better since public education attendance is very extensive

[15] Reasonably, one could endogenize the parameter ν in several ways, potentially as an increasing function of public school attendance ratio. However, there is no previous study or data that sheds light on the level of the public education spillover effect, and taking it as a parameter, possibly as a result of established institutions, is the more conservative way not to overstate complementarity benefits of relying heavily on public education. More on this issue is discussed in the next section.

for most of these countries, and the former model is not very suitable for this scenario.[16] Finally, the model where $\nu = 0.5$, coined as the hybrid model with limited public education spillover, is intended to study the environment where students who participate in private education can still benefit from the public education, yet not as much as the public school students. They can benefit from the public education level only at a fraction. [17] In reality, neither of the two polar cases are very likely, and a combination of the two is not only more reasonable, but also seems to fit better with the data, as shown in the results section.

As emphasized earlier since there are no aggregate shocks in the economy, the level of aggregate variables and the distributional properties of the variables of interest have to be stationary in the long-run equilibrium, which in turn implies that economy's tax rate determined by democratic elections stays at the same level at all times. This result enables studying the properties of the model with a major simplification. First, by solving the hybrid models for *given* tax rates, one can derive not only the values of aggregate variables and optimal decision rules of individuals, but also the life-time welfare of an individual at different tax rates. Next, by comparing an individual's welfare under different tax regimes, it is easy to show what would his most preferred tax rate be. Finally, combining the properties of the stationary distribution with the most preferred tax rates, one can investigate if particular tax rates can gain political support.

For the use of the above technique, next I define the stationary-equilibria of the hybrid models for given constant taxes.

3.4 Stationary Competitive Equilibria with Constant Taxes

The stationary recursive competitive equilibrium of the hybrid model under constant and exogenous taxes is a set of value functions, decision rules, and allocations such that

1. Given $\overline{H}$, $\overline{E}$, and τ, $c(h_t, \xi_t^i; \overline{H}, \overline{E})$, $l(h_t, \xi_t^i; \overline{H}, \overline{E})$ and $e(h_t, \xi_t^i; \overline{H}, \overline{E})$ are optimal decision rules to household agent i's problem, and $V^i(h^i, \xi^i; \overline{H}, \overline{E})$ is the resultant value function:

$$V_t^i(h_t^i, \xi_t^i; \overline{H}, \overline{E}) = \max_{\{c_t^i, l_t^i, e_t^i\}} \left\{ u(c_t^i) + v(1 - l_t^i) + \rho \mathrm{E}_t V_{t+1}^i(h_{t+1}^i, \xi_{t+1}^i; \overline{H}, \overline{E}) \right\} \tag{19}$$

subject to

$$c_t^i = (1 - \tau)\Theta {l_t^i}^{1-\lambda} {h_t^i}^{\lambda} - e_t^i \tag{20}$$

[16] To exemplify the extensivity of public education institutes in Scandinavia, an examination on the composition of Nordic European universities reveal that there are not any private universities in Finland or Sweden. In Denmark, the only type of universities that are private are business schools, and in Norway, no less than 90% of the students attend public universities. Iceland, being a small outlier among the Nordic countries has more private universities, yet overall public higher school attendance is no less than 80%.

[17] Due to the lack of information on the value of public education spillover, ν is set to 0.5, i.e. equally distant from the two polar cases.

$$e_t^i \geq 0 \tag{21}$$

$$h_{t+1}^i = \begin{cases} \xi_t^i(\overline{E})^{\varepsilon}((1-l_t^i)h_t^i))^{(1-\varepsilon)\gamma}\overline{H}^{(1-\varepsilon)(1-\gamma)} & e_t^i = 0 \\ \xi_t^i(e_t^i + \nu\overline{E})^{\varepsilon}((1-l_t^i)h_t^i)^{(1-\varepsilon)\gamma}\overline{H}^{(1-\varepsilon)(1-\gamma)} & e_t^i > 0 \end{cases} \tag{22}$$

2. All aggregate variables stay constant at all periods:

$$H_t = H_{t+1} = \ldots = \overline{H} \tag{23}$$

$$Y_t = Y_{t+1} = \ldots = \overline{Y} \tag{24}$$

$$C_t = C_{t+1} = \ldots = \overline{C} \tag{25}$$

$$L_t = L_{t+1} = \ldots = \overline{L} \tag{26}$$

$$\overline{E}_t = \overline{E}_{t+1} = \ldots = \overline{E} \tag{27}$$

3. Aggregate resource constraint holds:

$$\overline{Y} = \overline{C} + \overline{E} + \int_0^1 e^i di \tag{28}$$

4. Government runs a balanced budget, markets clear and definitions hold:

$$\overline{E} = \int_0^1 \tau(\Theta {l_t^i}^{1-\lambda} {h_t^i}^{\lambda})di \tag{29}$$

$$\overline{H} = \int_0^1 h_t^i di \tag{30}$$

$$\overline{Y} = \int_0^1 y_t^i di \tag{31}$$

$$\overline{C} = \int_0^1 c_t^i di \tag{32}$$

$$\overline{L} = \int_0^1 l_t^i di \tag{33}$$

5. Innate cognitive capability follows its exogenous log-normal law of motion:

$$\log(\xi^i) \sim N(\mu_\xi, \sigma_\xi^2) \tag{34}$$

Derivation of analytical solutions for the stationary equilibria is not feasible, and a natural candidate for computational solution is the use of value function iteration, which I employ for deriving the optimal decisions of the agents. Further, due to the absence of aggregate shocks, Huggett's (1993) algorithm is well-suited to solve the stationary competitive equilibrium computationally, details of which I discuss in the appendix.

To derive some results, I make the following fairly restrictive assumption for computational simplicity: Although taxes are known to alter labor choice in theory, I fix amount of labor supplied by all middle-aged individuals. I also normalize the utility from leisure $v(1-\overline{l})$ to zero. In a later section, I relax this assumption, and show that main results do not differ significantly under fixed-labor assumption.

4 Results

In this section, I first display my findings on the behaviors of micro and macro variables under different tax regimes with the hybrid model with no public education spillover. Next, I report some comparative statics with alternative parameter values to illustrate how different channels affect the variables of interest. Then, I analyze real world evidence, and discuss the drawbacks of the model with no public education spillover. Next, I display the results from the hybrid models with maximum and limited public education spillover, and investigate how well the latter model fits with data. Then, I drop the fixed-labor assumption and compare how variables of interest behave with endogenously-determined labor. Finally, I analyze the welfare of agents over taxes.

4.1 Benchmark Results of the Hybrid Model with No Public Education Spillover

The benchmark parameter values I employ in the hybrid models are displayed in Table 5. Following Benabou (2000), I set the value for the share of human capital (λ) to 0.625, mean and standard deviation of initial logarithm of human capital values(μ_h and σ_h) to 0 and 1, and mean and standard deviation of logarithm of in-born cognitive competence values (μ_ξ and σ_ξ) to 0 and 1. Following Zhang (2005), I set the elasticity of human capital with respect to parental time-away from work (γ) to 0.2, the altruism rate (ρ) to 0.8, and the total factor productivity coefficient (Θ) to 5. In the literature, the elasticity of human capital with respect to education (ϵ) varies between 0.15-0.4. I assign a value close to the mean, 0.3, so as to roughly match the share of public education to total education for the U.S. and Nordic targets at their relative per-capita output values. Also, for the utility, I employ natural logarithmic utility function.

In Figure 5, I show the simulated values for aggregate human capital over the course of time under four different tax regimes $\tau = 0\%$, $\tau = 4.5\%$, $\tau = 10\%$, $\tau = 15\%$.[18] For each of these four regimes, aggregate human capital, as well as the other aggregate variable series are observed to be stationary and almost constant, except for very minor fluctuations due to approximation errors in computational calculations.

In Figures 6-9, I display the value functions at individual-specific human capital and in-born productivity state pairs under the four tax regimes. The value functions are observed to be smooth, concave and increasing in both dimensions.[19] Comparing the values under four regimes, the highest life-time utility is attained under the *laissez-faire* economy for the rich (high h and ξ pair) and high-tax environment $\tau = 15\%$ for the poor, as expected. In between the two tax rates, life-time utilities are lower when compared to the two extreme cases, with $\tau = 4.5\%$ tax regime generally generating higher values than $\tau = 10\%$. As tax rate goes up, the value function is observed to be more concave and less steep due to the redistributive nature of the taxes.

In Figures 10-13, I illustrate the decision rules at different h and ξ state pairs. Except for minor irregularities due to limited grid size, the education choices are also observed to be concave and smooth under the four tax regimes. There is a discrete jump in education choice under all the regimes but the *laissez-faire* economy, reflecting the public versus private education choice, i.e. the extensive margin. These jumps occur monotonically at higher individual human capital states as the tax rate goes up. Also, the minimum possible education attained, i.e. the respective public education in different regimes, are also monotonically increasing in tax rate. Finally, as the tax rate goes up, private education choice, i.e. intensive margin, decreases due to less disposable income, as well as lower return on education. Due to these properties of the decision rules, higher tax rates disincentivize private education both in the extensive and intensive margin.

Table 6 displays the behavior of aggregate variables under different tax regimes. Last three

[18] The reason I display these four regimes is that while $\tau = 0\%$ and $\tau = 15\%$ represent two polar cases of *de facto* pure public and private education,$\tau = 4.5\%$, $\tau = 10\%$ regimes represent the U.S. and Nordic countries, respectively. Details are presented in Table 6.

[19] Given that in-born productivity shocks are not persistent and mean-reverting, the values in different cognitive-competence states are only moderately different. On the contrary, individual-specific human capital is somewhat persistent due to limited intergenerational skill-transmission, which increases the responsiveness of the life-time utility function to the human capital state.

columns of Table 6 show that level of public education, share of public education in total education expenditure and share of population attending public schools are monotonically increasing in tax rate. These results are natural predictions that can be derived by looking at the decision rules depicted in Figures 10-13. The first three columns display a distinctly different pattern: As economy's tax rate goes up, average human capital, output, consumption, and total education first decrease, and after a threshold, they all start to increase. This result is displayed more explicitly in Figure 14. There is a clear U-shaped pattern in all aggregate variables. The threshold tax rate where aggregate variables are minimized is roughly at $\tau = 10.2\%$, and at this point and beyond, the whole population chooses to attend only public education.

Here is a brief explanation on why we observe the U-shaped dynamics of the aggregate variables. Starting from the *laissez-faire* economy, as the tax rate goes up, four factors are in effect, three of which in are against and one of which is in favor of aggregate variables: First, as a result of a higher tax rate, disposable incomes of the households decrease, which reduces the preferred private education by the changing through the intensive margin. These are the middle-aged agents who still choose to bequest private education to their kids, yet only at lower levels. Second, there is a disincentivizing extensive margin effect due to the level of public education. To exemplify this effect, suppose that in the absence of a public education level of 0.10 units, a middle-aged agent chooses to bequest 0.15 units of private education to her offspring. In the presence of the public education, instead of paying the full private education cost of 0.15 units, the middle-aged agent optimally chooses the public education level of 0.10 units, and does not bear any education financing costs. The presence of public education causes a decrease in the level of education attained by a change in the extensive margin for the individuals whose optimal private education choices would have been in the close neighborhood *above* the public education level. Third, there's a distortion to human capital investment caused by a lower return on education. When compared to a lower tax rate, with a high tax rate, the same level of education generates equal pre-tax output, but less post-tax disposable income, which discourages education attainment. These three effects, due to reducing educational bequests, cause aggregate education to decrease, which in turn decreases the level of human capital; and given that production takes place with human capital and fixed labor only, lower aggregate human capital causes lower output and consumption accordingly. The fourth effect, which works in favor of the aggregate variables is due to the extensive margin choice of the poor. In the absence of public education, those who choose a private education bequest below the public education level would choose to attend public education when it is available. Accordingly, the presence of public education make the poor better off by having them increase their education level through the extensive margin, which in turn increases aggregate education, human capital, output and consumption. All these four effects are amplified by the presence of complementarities in the economy.

Unless whole population attends public education, the former three negative effects dominate the positive effect. The reason can be described as follows: Suppose that the economy is at the threshold tax rate $\tau = 10.2\%$ where whole population attends public education. If tax rate decreases by an infinitesimal amount, some small measure of the population will choose to exit public education pool, and attend private education. At this tax rate, the private education they choose to pick must be much higher than the public education level so that they would be willing to bear full cost private of education. Then, those who choose to bequest private education would increase total education acquired in the economy, which in turn increases aggregate human capital, and output. As the tax rate goes down, there is also a negative effect in act: Due to lower tax rate, public education level goes down, which decreases the education attainment of a major fraction of the population. However, since the tax decreases only marginally, and those who choose private education still keep funding the public education system anyway, the drop in public education level is negligibly small, and is more than offset by the increase in private education attainment of the rich. As a result of these channels, aggregate education increases as tax rate drops marginally. As total education goes up, so does aggregate human capital, and output. If the tax rate increases beyond the threshold tax rate $\tau = 10.2\%$, public education level goes up, and since there would be no change in the extensive margin of any of the individuals, aggregate education goes up, too, which in turn increases human capital and output.[20] Therefore, in the presence of distortionary taxes to finance public education, to maximize aggregate output, a social planner either needs to set the tax rate to 0% or high enough (e.g. 15%) so that the complementarity effect can dominate the distortionary effect of taxes and disincentivizing effect of high public education level, i.e. higher provision of public education reducing the incentive of individuals to choose higher levels of private education spending for their children.[21] Hence, instead of an education system where both public and private education are chosen by some measure of households, or taking the "middle road", it is aggregate-variable-enhancing to rely extensively on of the the two types of educations.

In Table 6's third row where the economy is under the constant 4.5% regime, the share of public education expenditure to total education expenditure is 32.34% and in the sixth row, the

[20] When the whole population attends public education, with no intergenerational skill transmission, i.e. $\gamma = 0$, aggregate human capital in the economy can be derived implicitly by $\overline{H} = (\int_0^1 h^{i(1-\lambda)\varepsilon})^{1/\varepsilon}\tau\Upsilon$ where Υ is a constant. Since beyond the threshold $\tau = 10.2\%$ distribution of human capital across individuals do not change substantially in terms of higher moments, by looking at the implicit characterization equation, one can see that aggregate human capital increases in tax rate.

[21] As the tax rate goes up beyond 10.2%, aggregate output keeps increasing with no limit. This result is due to the fact that I impose the restriction that labor is supplied inelastically at $\bar{l} = 0.33$. In fact, as the tax rate goes up, economic theory suggests that due to the distortion in the labor wedge, labor supply should decrease. For low enough tax rates, tax rate discrepancy between the U.S. and the Nordic countries decreases usual hours worked minimally, as referred earlier to Alesina *et al* (2005). For high enough tax rates, however, the inelastic supply is to be modified to reflect labor supply decrease.

share of public education expenditure is 95.77%. Further, the ratio of per-capita output in 10% tax regime to per-capita output in 4.5% tax regime is 74.1%. As shown in Table 2, in reality the ratio of public to total education expenditure in the U.S. is 32.26% and the same ratio for Nordic country average is 93.83%. Further, according to Penn World Data 6.3, the long-run average per-capita output in the Nordic country average is 76.71% of the U.S. per-capita output. In the light of these findings, one can think of the 4.5% tax rate economy mapping from the model to the U.S. and a tax rate slightly below 10% tax rate economy matching to the Nordic average. In this regard, the model can match the empirical discrepancies by a 5.5% difference in tax rates.

Next, I focus on inequality measures that the model generates under different tax regimes, and display my findings in Table 7. Specifically, I calculate the gini coefficients of the variables of interest at a given period across individuals under different tax rate regimes. My results suggest that as economy's tax rate goes up, so does inequality in human capital, output and education up to a threshold of 4.5%. Beyond this tax rate, gini coefficients for these variables of interest start to decrease. For human capital and output, they stay constant after the whole young population attends public schools, and for education since everyone attends public schools anyway, there is no disparity across households, thus the education gini is zero. Regarding the inequality in consumption, there is not much variation under different tax rates: As tax rate goes up, a significant fraction of people start to attend public education, which is significantly lower than the private education average, thus those attending public education have lower human capital and produce less, which increases inequality. At the same time, as the rich middle-aged choose high level of private education for their kids, they incur high costs of education financing which they have to pay out of their pockets fully, as opposed to public school parents. That the rich pay higher absolute amounts of taxes and private education costs moderate consumption inequality. Due to these offsetting effects, there is not much variation in inequality for consumption. Further, as tax rate gets high enough so that everyone attends public education, consumption becomes only a fraction of output, and inequality in consumption remains similar to the inequality in output. To show the effect of taxes on the inequality of variables of interest, I display the Lorenz curves under different tax regimes in Figures 15-18. Noticeably, the most radical change in inequality among these variables is in education, followed by human capital. These findings are in accordance with higher income and educational inequality predictions of the U.S. when compared to the Nordic European countries.

To see how well the model maps with data, not only for the U.S. and Nordic Countries, but also with remaining developed economies, I do the following exercise: I sort the the developed economies whose data is available with respect to their public-to-total-higher-education shares in an ascending order, and plot them jointly with of GDP (PPP) per capita data. I also add these countries' taxes on income and profits and total tax revenue as a percentage of GDP, and illustrate my findings in Figure 19.[22] First, there is a noticeable slightly-distorted U-shaped pattern of per-capita output over public education shares. I derive and plot also the filtered per-capita output values, which can strike the U-shaped pattern better. I also plot the tax rate trends, and illustrate that although there are some fluctuations, tax shares tend to increase when public-to-total education share goes up, total tax revenue to GDP ratio acting more in accordance with the trend than the taxes on income and profits to GDP ratio. Therefore, it is possible to conclude that the U-shaped pattern generated by the model over taxes is also observable in data.

When comparing the results suggested by the model to the data, an important mismatch is noticeable though. While the hybrid model with no public education spillover reaches the output-minimizing tax rate when the whole young population attends public education, the data suggests the minimizing point is significantly below 100%, close to 60% to be exact. This drawback of the model is very unlikely to be fixed by altering parameter values in a reasonable range. Instead, the benefit of public education to private school students, or opportunity cost of private education should be revisited, which I do next by introducing the two further hybrid models. But, before that, I present some comparative statics with alternative parameter values to illustrate how different channels affect the results.[23]

4.2 Comparative Statics of the Hybrid Model with No Public Education Spillover

4.2.1 Absence of Idiosyncratic Shocks

In the absence of idiosyncratic shocks, i.e. $\sigma_\xi^2 = 0$, all households become identical, and stationary values of macro variables decrease substantially at all tax rates, as shown in Table 8. This result is similar in spirit to the well-known "precautionary saving" incident. When there is uncertainty on the in-born cognitive capability of future generations, the middle-aged find it optimal to accumulate "precautionary human capital" some fraction of which they could pass to their pupils in the absence of physical capital. Accordingly, in the lack of future shocks, the middle-aged find it optimal to bequest less education, which results in less human capital, output and consumption. Since the absence of uncertainty also removes heterogeneity, the fraction

[22] Given that developed countries differ substantially on their tax schemes by use of very complicated tax instruments, such as tax brackets, tax deductable income and expenditure, progressivity, etc., instead of ranking them with respect to tax rates, I sort them with respect to public-to-total education shares, which is a more objective and standardized measure across countries, and is an endogenous outcome of the hybrid model.

[23] I analyze that the same qualitatively comparative statics results hold for all three hybrid model specifications. I omit the results of comparative statics of the two latter models for brevity.

of population acquiring public education is either zero (at low tax rates) or one (at high enough tax rates). The U-shape of the aggregate variables are preserved since the distortionary effect of taxes is still present.

4.2.2 Higher Return of Education on Human Capital

When the elasticity of human capital with respect to education doubles, i.e. $\varepsilon = 0.60$, the levels of all aggregate variables increase at all tax rates, as shown in Table 9.[24] From the middle-aged agents' point of view, education is a choice variable, as opposed to intergenerational skill transmission or aggregate complementarity. Therefore, higher return of education on human capital incentivizes the middle-aged to bequest more education, which causes a level shift in all aggregate variables. Further, since education is more effective now, an increase in the tax rate does not discourage the middle-aged to reduce their private education as much as in the benchmark case, and this causes less share of population to go for public education at same incremental tax increases. Thus, although the U-shape is still preserved, the threshold tax rate where everyone attends public education is realized at a tax rate beyond 15% as opposed to 10.2% in the benchmark case.

4.2.3 Absence of Complementarity Effect of Aggregate Human Capital

The absence of economy-wide complementarity of aggregate human capital, i.e. $\gamma = 1$, causes higher level of persistence in idiosyncratic human capital levels. In the presence of complementarity effect of aggregate human capital, when aggregate human capital is high, return on education gets higher, which in turn incentivizes the middle-aged to bequest more education, causing even higher aggregate human capital. In the absence of complementarity effect, there is higher intergenerational skill-transmission. Given that idiosyncratic shocks cannot change the level of average productivity in the economy, parental transmission effect cannot deliver the same amplification effect. Although a positive shock to a rich person can cause more persistent human capital in a dynasty, same holds for the negative shocks to the poor. Therefore, lack of complementarity causes the dismissal of the amplification effect, thus all macro variables to fall at all tax rates as illustrated in Table 10. Further, absence of complementarity causes less sharp response of aggregate variables to increases in tax rates due to the lack of amplification, and this causes the minimum point of the U-shaped graph of macro variables to show up at a point beyond $\tau = 15$, around 30%. Accordingly, at a tax rate of $\tau = 15$, only 83.71% of the population chooses public education.

[24] For this and next two experiments, note that the law of motion for human capital is homogenous of degree one in education, intergenerational skill transmission and economy-wide complementarity, which implies that increase in one of the parameters would imply decrease in parameter values for the remaining ones.

4.2.4 Absence of Intergenerational Skill-Transmission Effect

No transmission of skills across generations, i.e. $\gamma = 0$, implies high complementarity effect of aggregate human capital in the economy, which causes opposite results compared to the absence of complementarity exercise. Individual responses are amplified through the presence of high complementarity, which causes a positive level shift in macro variables, as shown in Table 11. The same amplification mechanism causes a steeper decrease in the arms of the U-shape of the macro variables over taxes, but the U-shaped patter in preserved. Thus, as opposed to 10.2% in the benchmark case, the aggregate-variable-minimizing tax rate is observed be around 9.1%.

4.2.5 Lower Fixed Labor Supply

As briefly mentioned earlier, economic theory suggests that an increase in the distortionary tax rate would cause a decrease in the labor supplied by the middle-aged agents. Further, and there is a growing literature on why Americans supply more labor than Europeans.[25]. In the light of these insights, I conduct the experiment to derive stationary-equilibria with a lower inelastic labor supply, $\bar{l} = 0.25$. Although a lower fixed supply can be thought as a negative shift in the technology parameter which decreases aggregate variables, the non-trivial aspect of this exercise is that a lower fixed supply would also imply more devoted time on parental education of the pupil, $1-\bar{l}$, which increases the effectiveness of education on human capital. As it can be seen in Table 12, in equilibrium the negative effect dominates the positive one, and there is a negative level shift at all tax rates while the U-shape of macro variables is preserved.

4.2.6 Persistent In-born Productivity Shocks

While economists model in-born productivity shocks in a non-persistent log-normal way for general equilibrium concerns (e.g. Bénabou, 2000, 2005; Zhang, 2005), geneticists show that heritability of IQ in the U.S. is measured to differ between 0.40 to 0.80 (e.g. Plomin *et al*, 1994). In the light of this evidence, I model innate cognitive capability stochastic process as a first-order autoregressive process with the same mean as follows:

$$\log \xi^i_{t+1} = \kappa \log \xi^i_t + u_{t+1}$$

where $u_{t+1} \sim N(0, \sigma^2_u)$ and $\sigma^2_u = \frac{\sigma^2_\xi}{1-\kappa^2}$ so that both models have the same mean and variance. I set the value of the autoregressive coefficient to a positive constant $\kappa = 0.40$, and report the results in Table 13. My findings reveal that while the U-shape is still preserved, there is a significant drop in the values of aggregate variables in all tax rates. When the in-born productivity

[25] Among others, see Alesina *et al* (2005), and Prescott (2004).

shocks are persistent, a household with a low productivity draw is likely to have a child with a low productivity, as well. Since his disposable income is low and next generations' productivity are probable to be low, as well, he is not motivated to bequest a high level of education to his child. For those with high in-born productivity draws, since high future generations are likely to have good draws as anyway, too much education is not necessary. Also lower educational bequests dampen aggregate human capital level, and accordingly due to complementarity effect, return on education gets lower, which amplifies the negative effects. These factors combined cause the negative shift of aggregate variables at all tax rates.

For the remaining parameters, I verify that increasing the share of human capital in the production function λ or the altruism (discount) rate ρ boost the level of aggregate variables at all tax rates while preserving the U-shaped pattern, as expected by economic theory.

4.3 Results of the Hybrid Model with Maximum Public Education Spillover

After analyzing the hybrid model with no public education spillover and how different channels affect results, next I derive the results for the hybrid model with maximum public education spillover, in which all students regardless of their education choice can benefit from the present public education level. The value functions and optimal decision rules are verified to be smooth and concave. Contrary to the former hybrid model case, however, for the non-zero tax rates where some measure of individuals find it optimal to attend only public schools, there are not any distinct jumps in the private education extensive margin (as in Figures 11 to 13), but smooth transitions.[26] This is because of the fact that, under this scenario an infinitesimal private education choice does not require giving up the benefit from the present public education level, and the only opportunity cost is the expenditure spent on private education.

Table 14 displays the behavior of aggregate variables under different tax regimes. First three and the fifth columns reveal that similar to the former hybrid model, there is still a U-shaped pattern, yet the minimum aggregate variable levels are far greater than those of the hybrid model with no public education spillover. Whereas the *laissez-faire* economy is identical to the former model case as it must be, incremental drops in aggregate variables as a result of higher taxes are only minor. Further, beyond the tax rate where aggregate variables are minimized, i.e. $\tau \approx 8\%$, the model generates higher aggregate variable results compared to the no-public-education-spillover case, even greater than the *laissez-faire* economy when tax rate is beyond 12%. These results are not surprising since the young in the model *de facto* get higher education at all tax rates compared to the former hybrid model, as they do not have to give up public education when private education is chosen.

[26] These graphs are omitted for brevity, and are available upon request, as are the other omitted materials.

The last three columns of Table 14 show that, while the level of public education at all tax rates beyond zero is greater in magnitude compared to the former model, the share of public education expenditure in overall education costs and the fraction of population attending only public education is much lower at all tax rates. Specifically, no one attends only public education until tax rate goes above 6%, and while almost the whole population attends public education in the former hybrid model when tax is 10%, lower than one-third of the population finds it optimal to choose public education in this model. Again, this implication of the model can be attributed to the lower opportunity cost of private education. The details of the behaviors of aggregate variables over taxes can be analyzed in more detail in Figure 20.

Table 15 illustrates the distributional properties of macro variables at different tax rates. While the gini coefficients of aggregate human capital and output stay roughly the same up to $\tau = 7.5\%$, they start to decrease beyond this tax rate. Further, the gini coefficients of consumption and education are observed to decrease monotonically over tax rates. Therefore, it could be inferred that the hybrid model with maximum public education spillover generates less unequal distributions of major variables across households almost monotonically over tax rates contrary to the former hybrid model, which generates more unequal distributions over tax rates up to a threshold of 4.5%.

Although the hybrid model with maximum public education spillover generates admittedly unrealistic predictions, a promising element it suggests is that the model succeeds to reach the aggregate-variable-minimizing tax rate at a point where only a very minor fraction of the population attends public education. With this result at hand, it is reasonable to predict that a hybrid model with a convex combination of the two polar cases in terms of public education spillover can generate more realistic and logical results. I show that such predictions can be verified next.

4.4 Results of the Hybrid Model with Limited Public Education Spillover

In this section, I report and discuss about the results from the hybrid model with limited public education spillover, in which students who attend private schools can benefit from the present public education level only partially ($\nu = 50\%$) . Again, the value functions and optimal decision rules are confirmed to be smooth and concave, and there *are* distinct jumps observed in the private education extensive margin for tax non-zero tax rates, as in the no-public-education-spillover model. This result can be attributed to the presence of opportunity cost of private education on top of the finance costs: When students attend private education, their parents not only have to bear the private education costs but also incur an additional cost of giving up half of the present level of public education. For those who choose private education for their kids, the benefits must exceeds the sum of the two costs, and this causes the distinct jumps in optimal choice, similar to those in Figures 11 to 13.

Table 16 summarizes the results from the model. The first three and the fifth columns show that similar to the former two hybrid model results, aggregate variables display a U-shaped pattern. The depth of the U-shape is greater than the maximum-public-education-spillover, but lesser than the no-public-education-spillover models. Again, this result is due to the fact that the young in the model *de facto* get higher education than the first but less than the second hybrid models at almost all tax rates.

A comparison of the output per capita over tax rates generated by the three models are displayed in Figure 21. The *laissez-faire* economies of the three models are identical since modeling public education spillover is irrelevant at this point where public education is zero. As tax rate goes up, the first hybrid model generates the lowest, and the second hybrid model generates the highest per-capita output. The limited spillover model lies in between the two polar cases up to the tax rate $\tau \approx 13\%$ where the whole population attends to public schools. Beyond this tax rate, since every young attends to public schools in both the no-spillover and the limited-spillover economies, the two models converge to the same per-capita output level. The intuition behind this result is similar to the *laissez-faire* example: Given that *de facto* there is only public education attainment, modeling how public education level affects private school students is irrelevant. At this tax rate, in the maximum-spillover model only half of the young attend public schools while the private school students still benefit from the public education level, which causes higher per-capita output compared to the other two hybrid models. These three models would presumably converge when the whole population in the maximum-spillover model attends only to public schools.

Focusing back to Table 16, contrary to the two other hybrid models, macro variables have a more prolonged base with minor fluctuations in terms of the U-shape. This result suggests that for a noticeable range of tax rates, roughly between 7.5%-12.5%, a slightly modified version[27] of the three negative and one positive effects of higher taxes described in the benchmark result section offset each other, and as a result, aggregate variables do not change significantly. The last three columns reveal that, the level of public education at all tax rates are above the no-spillover, but below the maximum-spillover models whereas the fraction of population attending public schools are vice versa. Further details of the behaviors of macro variables over tax rates can be seen in Figure 22.

Next, I analyze the distributional properties of the variable of interest and summarize my

[27] In the no-spillover hybrid model, the second negative effect, i.e. disincentivizing extensive margin effect of public education, was applicable for the scenario in which private education choice of the young necessitate to forgo all public education benefits. For the limited-spillover model, only half of the benefits are to be forgone when private education is chosen, hence the term "slightly modified" when describing the factors in act.

results in Table 17. First, second and the fourth columns reveal that, similar to the no-spillover model, human capital, output and education inequalities first increase as economy's tax rate goes up, and after a threshold of roughly 5%, they all start to decrease. Further, third column shows that consumption across individuals behave similar to the first hybrid model both in terms of the pattern and the magnitude. Consumption inequality initially decreases over tax rates, and after a threshold roughly 12%, it first increases very slightly, then stabilizes when the whole young population attends to only public schools. Overall, it can be inferred that distributional properties of macro variables derived from the limited-spillover model resemble the first hybrid model more than the second one.

After analyzing the behaviors of variables of interest, next I compare how well results generated by the hybrid model with limited public education spillover fit to the data. First, I interpolate the results for the limited number of tax rates and get finer measures for all variables of interest, then I match interpolated economies to the OECD economies listed in Figure 19 with respect to their share of higher public education expenditure to total higher education expenditure. I normalize the U.S. per-capita output to the correspondent equilibrium per-capita output, and depict the model's predictions on per-capita output at different tax rates together with the data. Figure 23 shows that both the model and data illustrate a decreasing per-capita output pattern over public-to-total-education-expenditure ratio, and if the filtered GDP per-capita is compared to the model's output, both reach their respective minimum around 60% share, although the minimum generated by the model is much more prolonged and lies above what the data suggests. Although not to scale, the model succeeds to generate the left arm of the U-shape fairly well. Beyond 60% share, whereas the model suggests roughly constant output per-capita for a large public expenditure share range, there is a clear upward pattern in the data. The perceivable part of the right arm of the U-shape generated by the model starts only after Denmark, or roughly 96% public expenditure share, and keeps steadily increasing beyond this point as shown in Figures 21 and 22. Overall, it can be concluded that while the model succeeds to capture the initially-decreasing pattern in data fairly well, it does not have a very good fit for the increasing portion. Although, a formal calibration could enhance model's fit, it is very probable that countries differ substantially in terms of public-education-spillover rates, or ν, in the model. While one would expect that a country where the only type of universities is free public university to have a high spillover rate, as in Sweden or Finland, and a country where half of the higher education institutions are private to have a comparably low spillover rate, as in Portugal. Results in the earlier subsections show that high spillover values can generate higher per-capita output at a given tax, therefore using more realistic, preferably from micro evidence, parameter values when matching data could improve model's performance.

Another important result that can be observed from Figure 23 is that despite the fluctuations, countries' tax rates have an upward trend over the public-to-total-higher-education-expenditure rate. The fluctuations around the trend tend to lesser when total-tax-revenue-to-GDP ratio is considered. Given the complexity of tax instruments, variability of tax resources, etc., such fluctuations are only expected. I believe it is reasonable to infer that higher taxes tend to be accompanied by high public education expenditure ratios, as suggested by the model. Further, overall the model can capture the behaviors of macro variables for the developed economies at least to some extent.

Since the paper's prime motivation is to establish a model that can generate the structural discrepancies between the U.S. and the Nordic countries, next I compare the predictions of the hybrid model with limited public education spillover to the data of countries of interest and summarize my findings in Table 18. At their respective public-to-total-education, the model predicts Scandinavian average output to be 86% of the U.S. whereas this ratio was 87% in 2008 according to OECD online database. In this regard, the model can deliver the respective per-capita income level ratio with a very high precision. Also, while the tax rate on income and profits in Nordic average is roughly double of the U.S. rate in data, approximately so is this ratio predicted by the model. Further, whereas the data suggests that public education expenditure per student in Nordic countries is significantly higher than the U.S. in absolute terms, 155% to be exact, the model makes a similar prediction, only with an exaggerated ratio of 211%. Moreover, what we see in data is that, in comparison, the U.S. spends much more on higher education, and lower fraction of students attend public schools. Although not up to scale, the model can deliver the same results qualitatively. Finally, the anecdotal evidence suggests that education attainment inequality in the U.S. is noticeably greater than Scandinavian countries, and the model can generate this distributional property of education, as well. Therefore, it can be argued that the model can generate results that can match data in several grounds fairly well.

4.5 Results with Endogenous Labor

Having established the results with fixed-labor, next I turn to relaxing this fairly restrictive assumption and analyze the associated changes. I modify the utility function of the middle-aged agent i as $u(c) + v(1-l) = \log(c) - \phi\frac{l^{1+\omega}}{1+\omega}$. I set $\omega = 0.5$ so that Frisch elasticity of labor supply equals 2, as in the mainstream macro literature. I calibrated the multiplier before disutility of labor to $\phi = 2.138$ so that average labor of the model at the *laissez-faire* economy equals $l = 0.33$ as in the fixed-labor model. Also, I kept $\nu = 0.5$ so the the results are comparable to the limited public education spillover model which fits the data best among the three specifications.

The value functions and optimal decision rules are again verified to be smooth and concave for education, and distinct jumps observed in the private education extensive margin for tax non-zero tax rates are observed to present, just as in the fixed-labor model. Further, for the non-zero tax rates labor supply decision is documented to illustrate distinct jumps, as well: The middle-aged agents who choose public education for their offsprings supply less labor than those who choose private education, however the variation across individuals for a given tax rate is observed not to be substantial. This result that low-productivity individuals with convex disutility in labor work less is in accordance with economic theory.

Table 19 displays the behavior of aggregate variables over tax rate. The pattern of the behaviors of aggregate variables is identical to the previous model, except for aggregate labor, which decreases monotonically as tax rate goes up. Another observation from the table is that for the *laissez-faire* economy, although average labor is matched to the fixed-labor model, average human capital and accordingly average output are higher than those of the fixed-labor model. This result can be attributed to the fact that middle-aged agents with high human capital and inborn productivity shocks supply more labor, and more productive labor force increases overall human capital accumulation and production. One final critical observation from Table 19 is that, the targeted tax rates to match the U.S. and Nordic countries' public education expenditure shares are slightly higher than the fixed-labor model, although the differences being reasonably small, both of them being less than 0.25%. Further details on the behaviors of aggregate variables can be observed in Figure 24.

Next, I compare the behaviors of aggregate variables generated by the endogenous-labor model to those of the fixed-labor model, and display my findings in Figure 25. The first six graphs of Figure 25 reveal that all aggregate variables but labor are higher for the endogenous-labor model at low tax rates, and are lower for the high tax rates. The higher productivity of the endogenous-labor environment due to better allocation of labor and education is offset by the decrease in labor supply as a result of higher taxes. However, the differences of the aggregate variables are not substantial, and variables in percentages (the share of public education and the fraction of public students) are almost identical for the two models.

The model predicts that average labor supply in the U.S. to be 1.064 times greater than that of the Nordic average. According to Alesina *et al* (2005) in terms of "usual" hours worked which is defined as the most common weekly working schedule over a selected period of a person in *employment*, U.S. employees work 1.047 times more than their Scandinavian counterparts. If whole hours worked are considered, the ratio goes up to 1.242. Since the model presented here does not feature unemployment or contractual employment, the generated ratio by the model can be considered to fit reasonably with the data.

Table 20 shows the distributional properties of the model with the endogenously-determined labor by focusing on the gini coefficients. Noticeably, coefficients of human capital, output, consumption and education are almost identical to the fixed-labor model at all tax rates. Inequality in labor displays the similar U-shaped pattern in human capital and output: As tax rate goes up, labor supply inequality initially increases and starts to decrease beyond a threshold. This result is due to the aforementioned labor supply discrepancy between those who choose to differ in terms of public versus private education choice.

Overall it is reasonable to conclude that the former fixed-labor assumption does not distort model predictions significantly.

4.6 Welfare Analysis

After establishing the results for given tax rates, next I focus on how agents' welfare varies over tax rates. First, I show the stationary distributions of households over the individual human capital and inborn cognitive capability state pairs generated by the hybrid model with limited public education spillover for the tax rates that match the U.S. and the Nordic average economies. Next, I illustrate what preference individuals have on tax rates by deriving consumption equivalent gains or losses for the state pairs over tax rates. Finally, I describe whether the given tax rates that match country targets can gain political support.

In Figures 26 and 27, I illustrate how the middle-aged are distributed over the human capital and in-born productivity pairs for the calibrated economies of interest. Also, I add the respective average human capital levels of the economies as the transparent light purple surfaces. The figures reveal that for both economies, majority of the population has individual human capital levels below the economy average, and an important share is populated at the very low end of human capital states regardless of the in-born productivity draws. Further, due to the high degree of variance of the in-born cognitive shocks, a significant fraction of population is located at the two extremes of the in-born productivity states. The log-normal distribution property of the innate productivity shocks, together with the optimal decision rules yield such results that the majority of the population have less-than-average pre-tax incomes.

Then, I derive how an egalitarian welfare measure, which is calculated as the sum of life-time utilities of agents weighted by their respective measures, and aggregate consumption change over taxes, and display my findings in Figure 28. The egalitarian average welfare mimics aggregate consumption very closely, and illustrates a U-shaped pattern over taxes. Yet, it would still be erroneous to conclude that the *laissez-fair* tax policies or very high tax rate ones Pareto-dominate policies in between the two polar cases, and everyone is better off choosing the two extremes. In fact, next I show that it is not the case.

I analyze how life-time utility of individuals vary over taxes at state pairs, and display resultant graphs, together with a zero surface, in Figures 29-35. The former three graphs display how middle-aged agents' consumption equivalent gains over taxes for given levels of in-born productivity, and the latter four graphs illustrate gains for given levels of human capital. In particular, graphs display consumption equivalent gains or losses by the use of equivalent variation: In order to leave an individual at a particular state indifferent between moving from the zero tax environment to another tax rate economy, how much more (or less) consumption as a percentage of his *laissez-faire* consumption is to be compensated. A careful examination on Figures 29 to 31 reveals that similar to the behavior of aggregate variables, most preferred taxes for given in-born productivity states display a U-shaped pattern, although with a minor yet critical difference: The middle-aged agents whose human capital states are low and in-born productivity are not very high are better off at a tax rate between 3% to 3.5% compared to the *laissez-faire* economy, and the consumption equivalent gains are more pronounced for those at the very low end of the state pairs. Beyond this tax rate, life-time utility first decreases up of a tax rate of roughly 11% and start increasing after. While minor differences across states are observable, for those with low state pairs, the general behavior of welfare over taxes displays a U-shaped pattern with an additional downward arm at the very left. For those at high human capital or in-born productivity states, welfare initially decreases over taxes and start to increase after the threshold tax rate, $\tau = 11\%$, i.e. with an almost perfect standard U-shaped pattern with minor fluctuations at the base, comparable to those of the aggregate variables. Figures 32 to 35 also magnify this pattern from an another angle. Although contrary to the canonical Meltzer and Richards (1989) preferences over taxes, these results are not surprising: Those at the very end of income distribution prefer the presence of non-zero taxes up to a level on the left arm, but not too high so that the gains from the redistributive benefits of public education are not offset by the fall in aggregate human capital. Beyond this point, further increases in taxes have sharp negative effects on aggregate human capital, and benefits from incremental increases in public education levels are offset by the drops in aggregate human capital. Once the economy reaches a high enough tax rate, majority of the population chooses to attend public education, and positive complementarity effects are enjoyed again on top of the public education increases, and life-time utility increases over taxes again. While single-crossing property seems not to be globally applicable, it is observed to hold *locally* around the two peaks: Numerically, if an individual with a human capital (h^1, ξ^j) prefers $\tau = 3.5\%$ tax rate over $\tau = 0$, so does the individual with (h^2, ξ^j) pair with $h^1 > h^2$. Similarly, if the individual with (h^1, ξ^j) prefers $\tau = 11.5\%+$ to $\tau = 11\%$, so does the individual with (h^2, ξ^j) pair. Also, while tax rates below 3% give more life-time utility than 11% for all the individuals, such comparison is not immediately applicable for tax rates close to 15% from below.

In the light of these findings, the presence of adjustment costs over taxes, e.g. physical allocative costs due to restructuring education, psychological costs due to cognitive dissonance, internalizing social norms, etc., the model can rationalize political support for the targeted tax rates.[28] If the present tax rate in the economy targeted to match the U.S. is close enough to 3.5%, low-income agents in the economy, who constitute the majority, would not gain substantial welfare by moving to the very high tax rate zone of $\tau = 11.5\%+$ due to the adjustment costs and would be content with the present tax rate. For those low-income agents in the economy to match the Nordic average, if the present tax rate is more than $\tau = 11\%$ and the adjustment costs exceed the benefits of moving to the 3.5% tax rate economy, they could be willing only to increase the tax rate, although not too high to distort labor supply too much. Therefore, given that majority of the middle-aged agents have less-than-mean level of human capital, and those at the low end of the distribution have double-peaked equilibrium preferences, the two equilibria can gain political support in the presence of adjustment costs. Although far from formal, the mechanism described here could provide insights for the political support of the targeted equilibria.

5 Conclusion

In this paper, I concentrate on the structural differences between the U.S. and the Nordic European countries' higher education systems. I propose a heterogenous-agent OLG model with both public and private education options available in the choice set of agents, presence of economy-wide complementarities, limited spillover of public education when private education is chosen, and distortionary taxes for public education financing. I first show that the model can deliver the U-shaped pattern of per-capita output over public education expenditure shares in the data. Next, I show that the model can deliver many of the empirical differences between the U.S. and the Nordic European countries fairly well for given taxes. In particular, with an exogenous tax rate difference of roughly 7%, the model can match target countries' per-capita output ratios and public education expenditure shares with a very high precision. Further, the model can deliver greater higher education expenditure, higher labor and lower public school attendance ratios although not up to scale, as well as more unequal distributions of macro variables for the U.S. when compared to the Nordic countries. Next, I show that in the presence of even minor adjustment costs, the respective tax rates can gain political support. Finally, contrary to what has been put forward in the literature, the model predicts that more provision of public education does not monotonically decrease inequality.

[28] While analyzing the welfare of individuals over tax rates, off-the-equilibrium-path beliefs are not implemented, and welfare gains at different equilibria are investigated. Therefore, while it would be erroneous predict about politico-economic outcomes. However, with reasonable off-the-equilibrium-path beliefs, the model could be utilized to provide more insight on politico-economic outcomes, potentially explaining political support for the aforementioned targeted tax rates.

Despite its promising prospects, the model has some important drawbacks. In the model, some of the parameter values are set in accordance with the previous literature, which is very limited. Further research, preferably on micro level estimation on the parameter values could improve the reliability of model's predictions. Also, while the model can provide insights on how the two distinct equilibria can gain political support, it cannot not bring forward the sources of the divergence. Alesina and Glaeser (2004) show that there were not noticeable differences between the U.S. and the continental European countries in terms of redistributive policies back in 1870s. Except for some non-economic explanations, no previous study to my knowledge has succeeded to account for the divergence, including this paper. In spite of its drawbacks, the model presented in this paper can shed at least some light on the implications of the presence of two education types at the same time, as well as on how different complementarity and spillover channels are in act in a general equilibrium set-up.

Figures and Tables

Figures

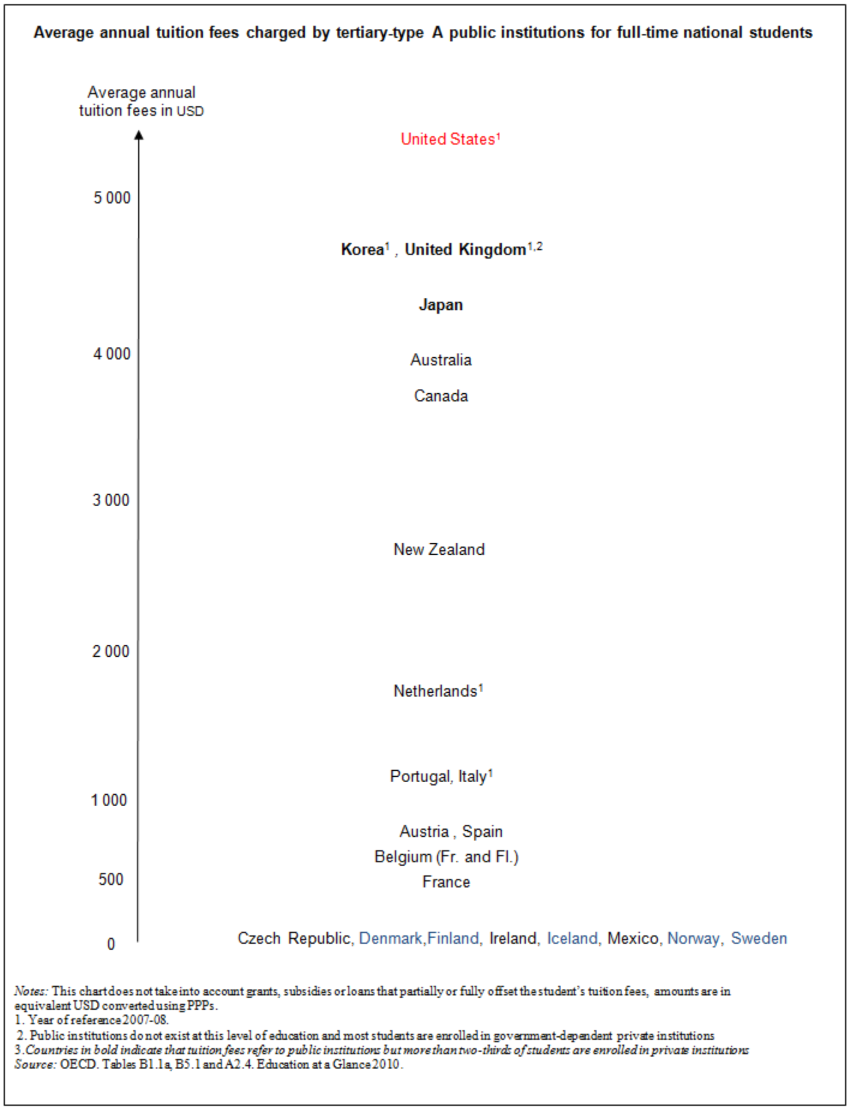
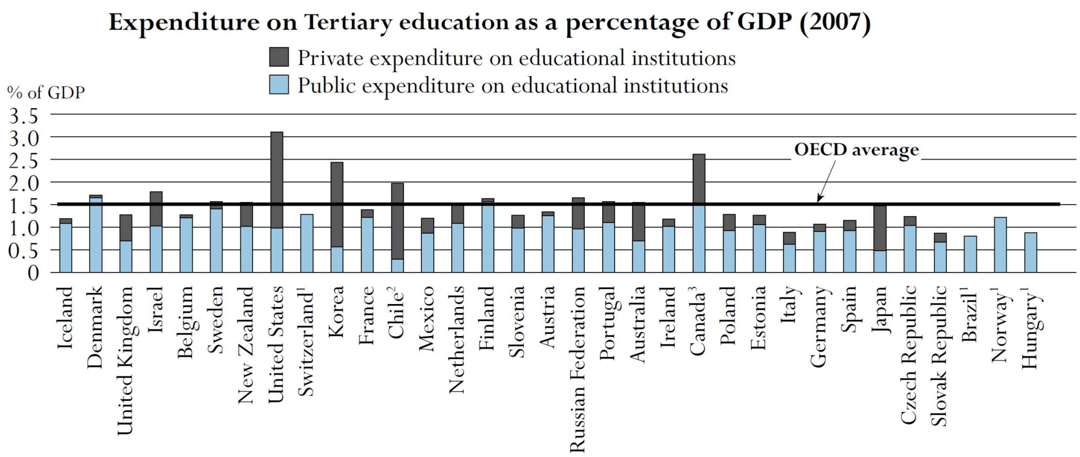


Figure 1: Average Public Tertiary Tuition Fees Across Countries

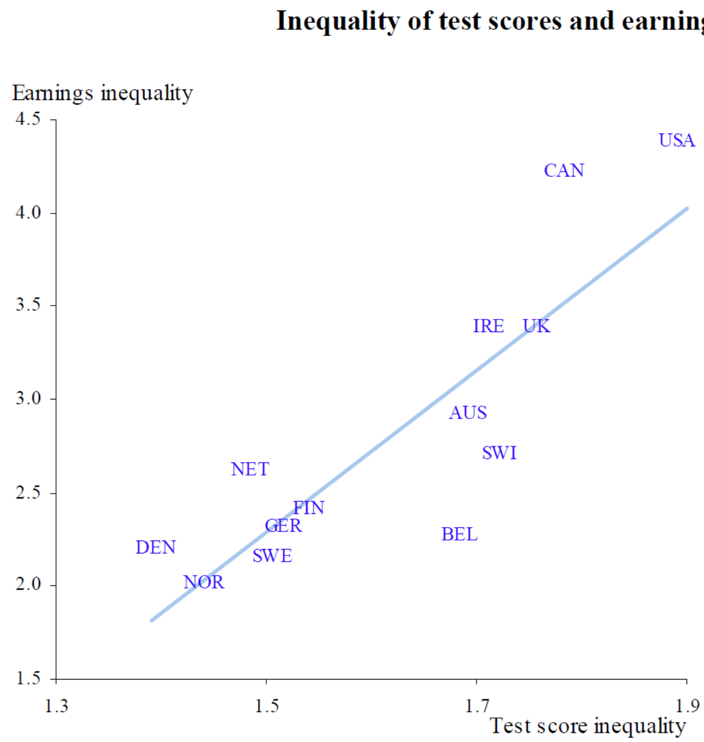


1. Public expenditure only (for Switzerland, in tertiary education only).
2. Year of reference 2008.
3. Year of reference 2006.

Countries are ranked in descending order of expenditure from both public and private sources on educational institutions in primary, secondary and post-secondary non-tertiary education.

Source: OECD. Table B2.4. See Annex 3 for notes *(www.oecd.org/edu/eag2010)*.

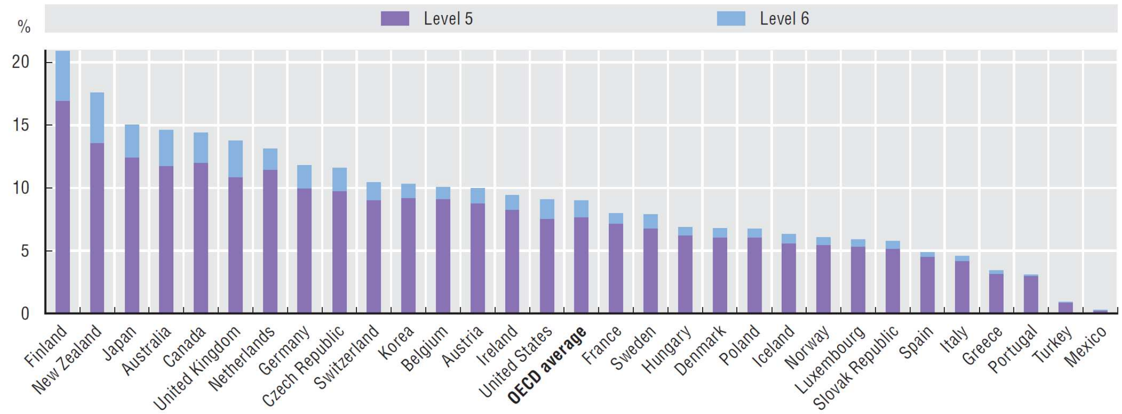
Figure 2: Higher Education Expenditure Across Countries



Notes: Measure of inequality is the ratio of ninth decile to first decile in both cases; test performance refers to prose literacy in the International Adult Literacy Survey.

Source: Based on Nickell (2004).

Figure 3: Return on Education and Literacy Score Inequality Across Countries



Source: OECD (2009), *Education at a Glance 2009*, Chart A4.1, available at *http://dx.doi.org/10.1787/664076271473*.

Figure 4: PISA Level 6 Scores Across Countries

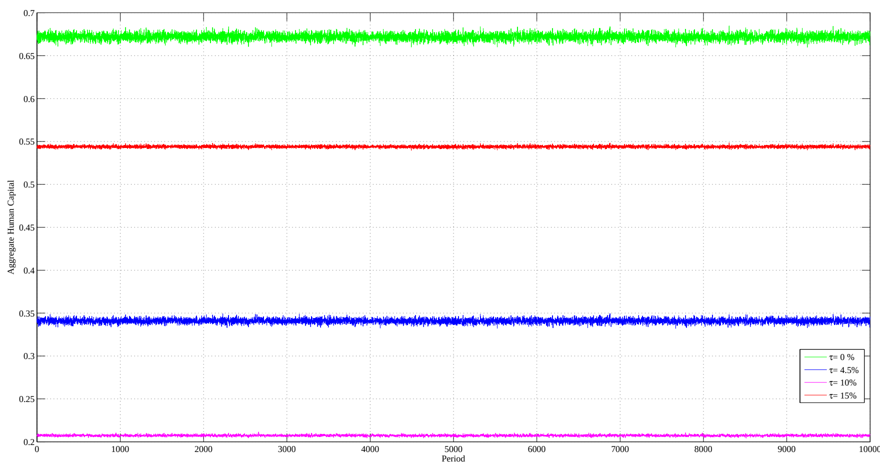


Figure 5: Aggregate Human Capital of the Hybrid Model with No Public Education Spillover under Four Tax Regimes

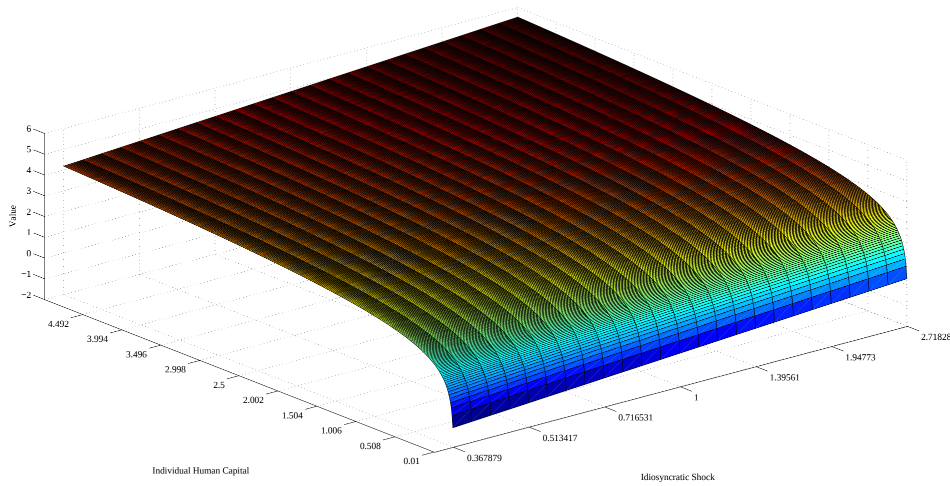


Figure 6: Value Function of the Hybrid Model with No Public Education Spillover When $\tau = 0\%$

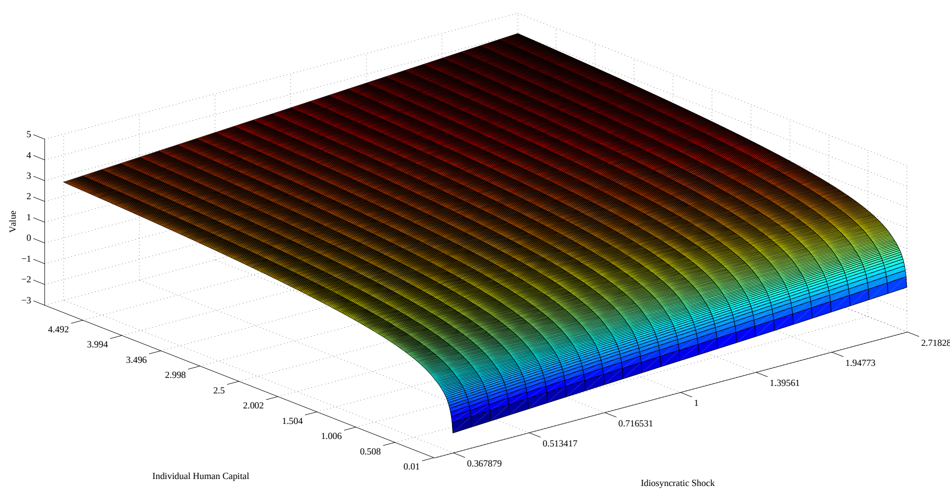


Figure 7: Value Function of the Hybrid Model with No Public Education Spillover When $\tau = 4.5\%$

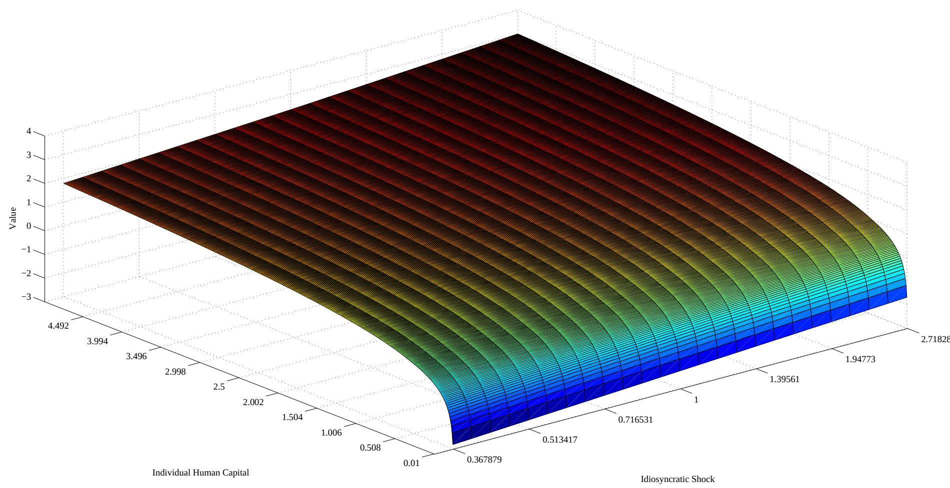


Figure 8: Value Function of the Hybrid Model with No Public Education Spillover When $\tau = 10\%$

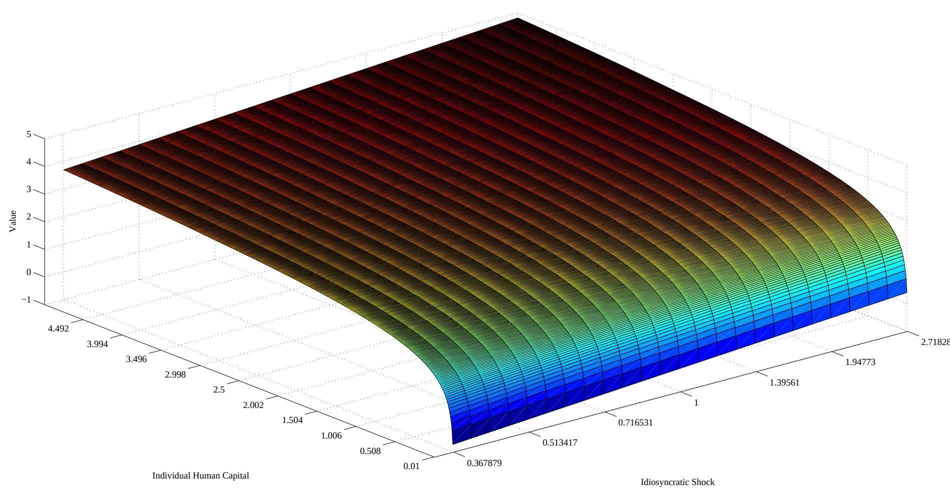


Figure 9: Value Function of the Hybrid Model with No Public Education Spillover When $\tau = 15\%$

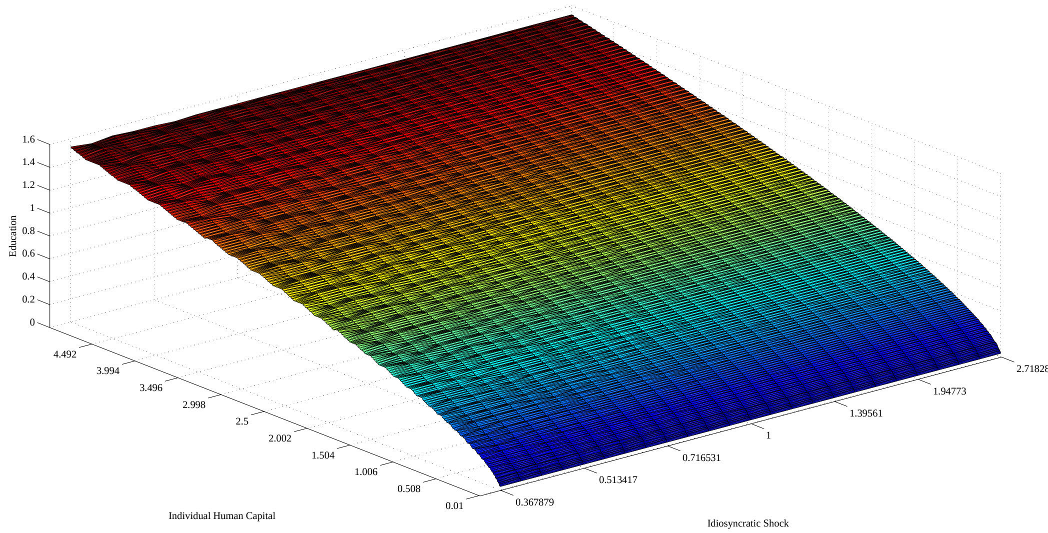


Figure 10: Education Choice of the Hybrid Model with No Public Education Spillover When $\tau = 0\%$

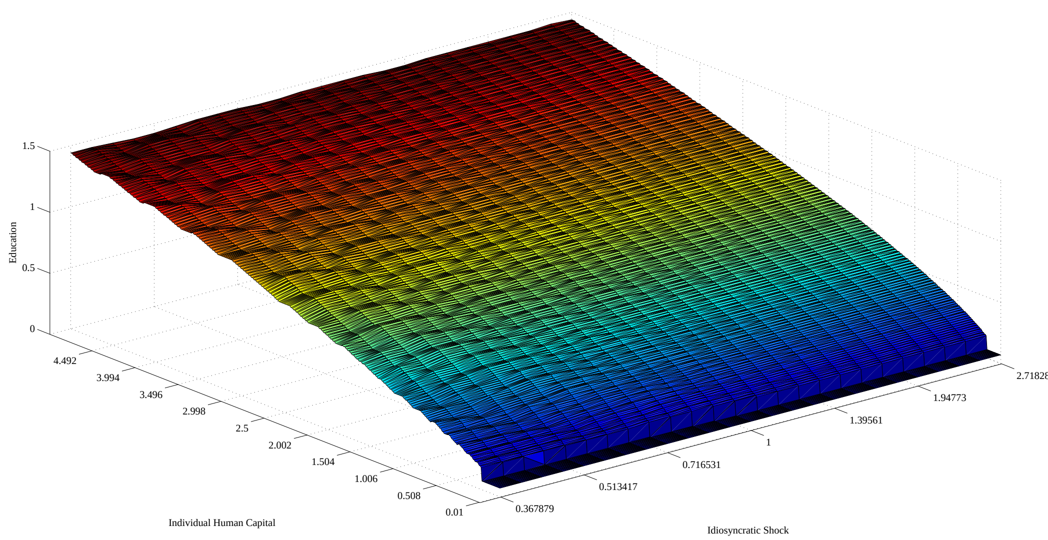


Figure 11: Education Choice of the Hybrid Model with No Public Education Spillover When $\tau = 4.5\%$

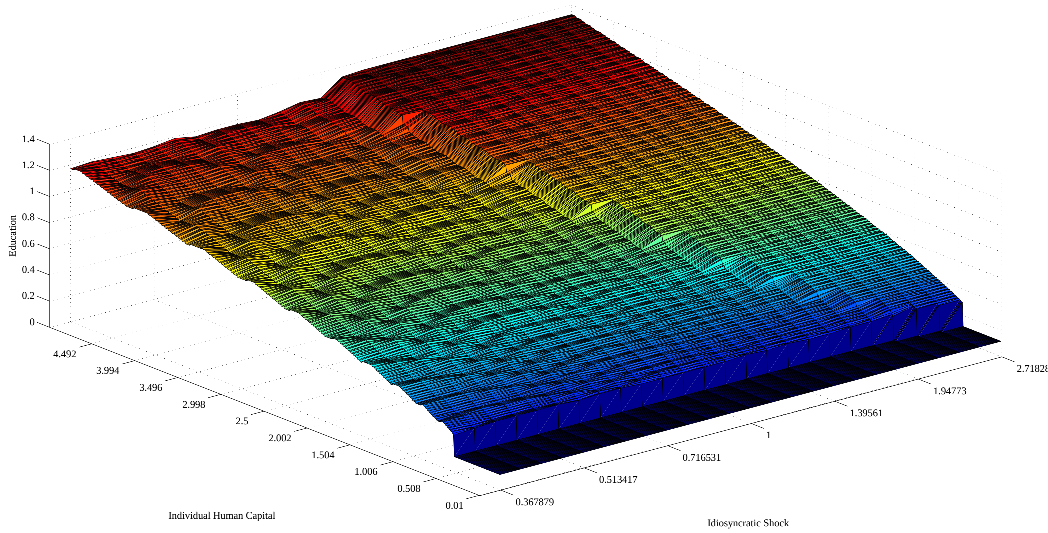


Figure 12: Education Choice of the Hybrid Model with No Public Education Spillover When $\tau = 10\%$

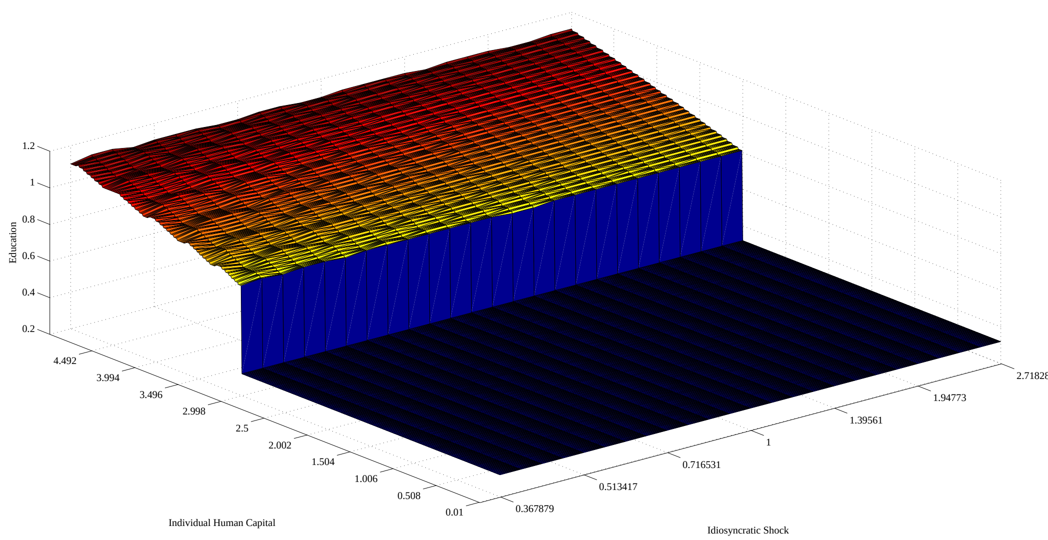


Figure 13: Education Choice of the Hybrid Model with No Public Education Spillover When $\tau = 15\%$

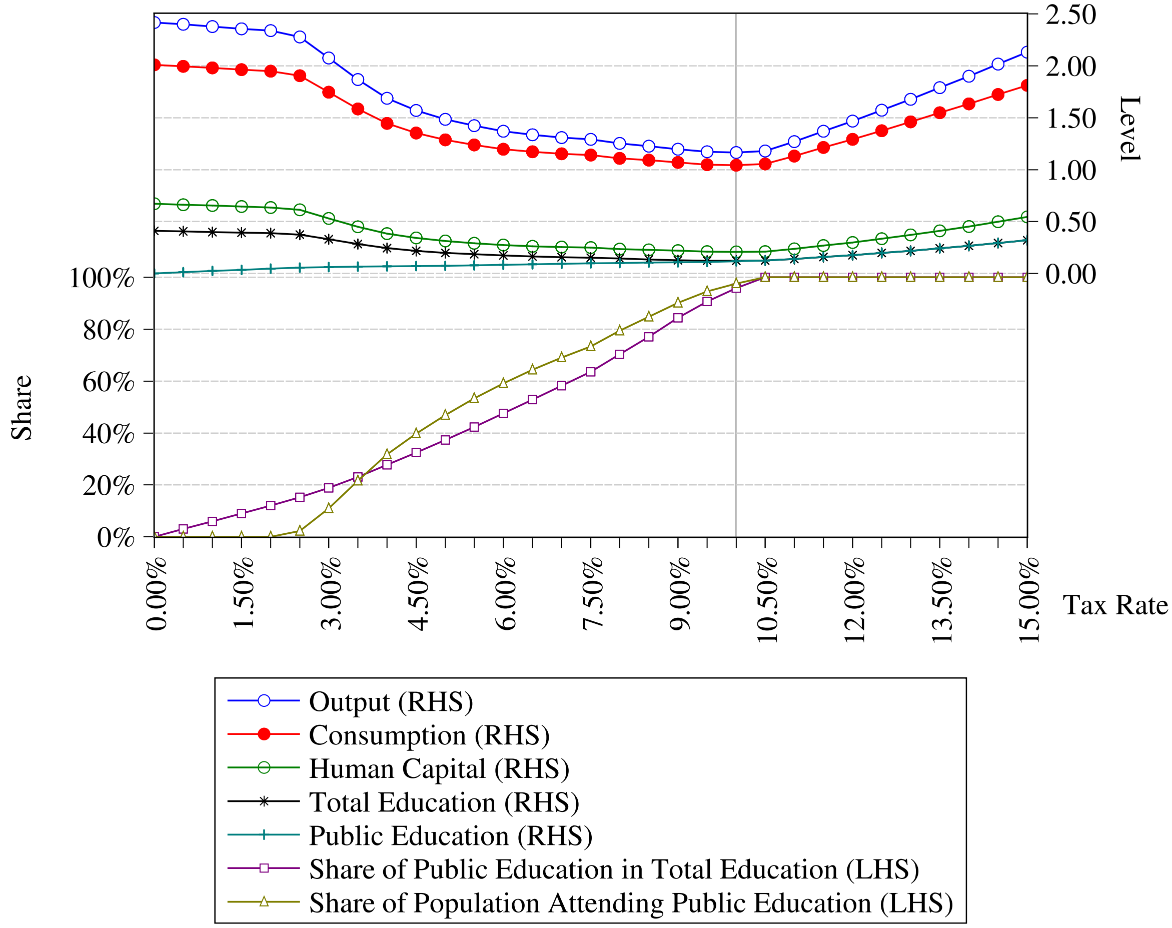


Figure 14: Stationary-Equilibria of the Hybrid Model with No Public Education Spillover

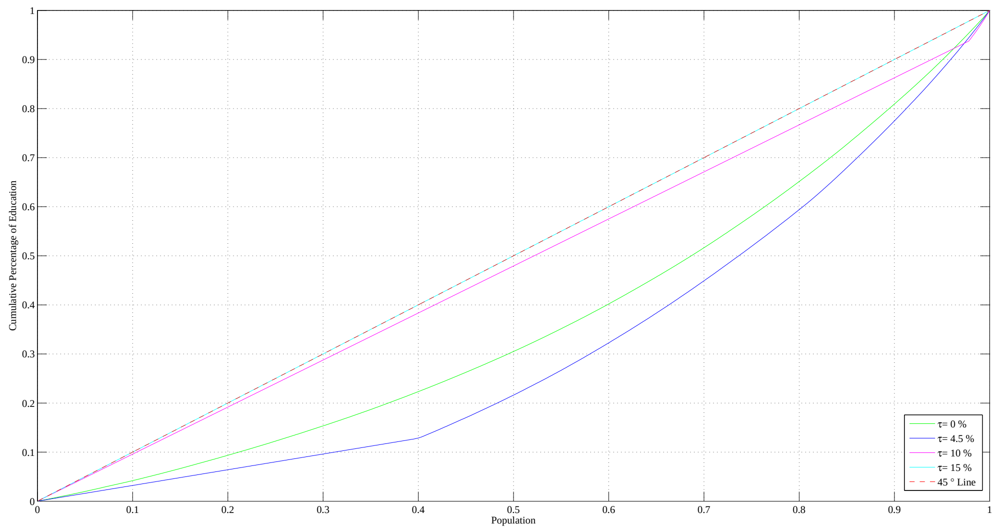


Figure 15: Lorenz Curves for Education of the Hybrid Model with No Public Education Spillover under Different Tax Regimes

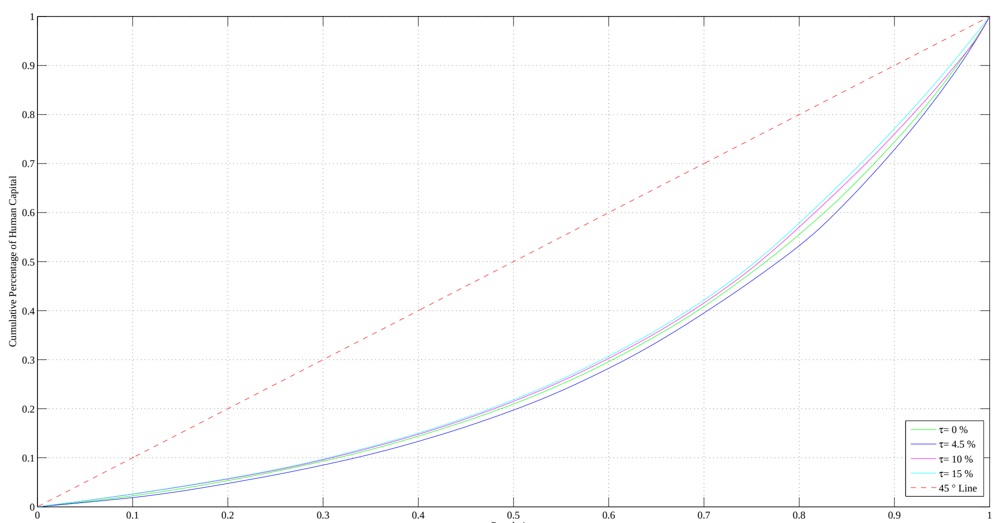


Figure 16: Lorenz Curves for Human Capital of the Hybrid Model with No Public Education Spillover under Different Tax Regimes

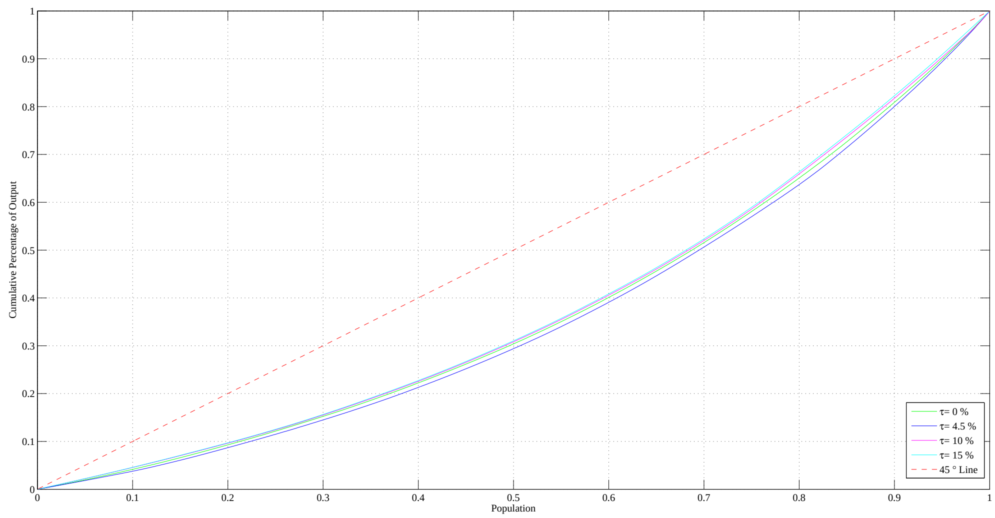


Figure 17: Lorenz Curves for Output of the Hybrid Model with No Public Education Spillover under Different Tax Regimes

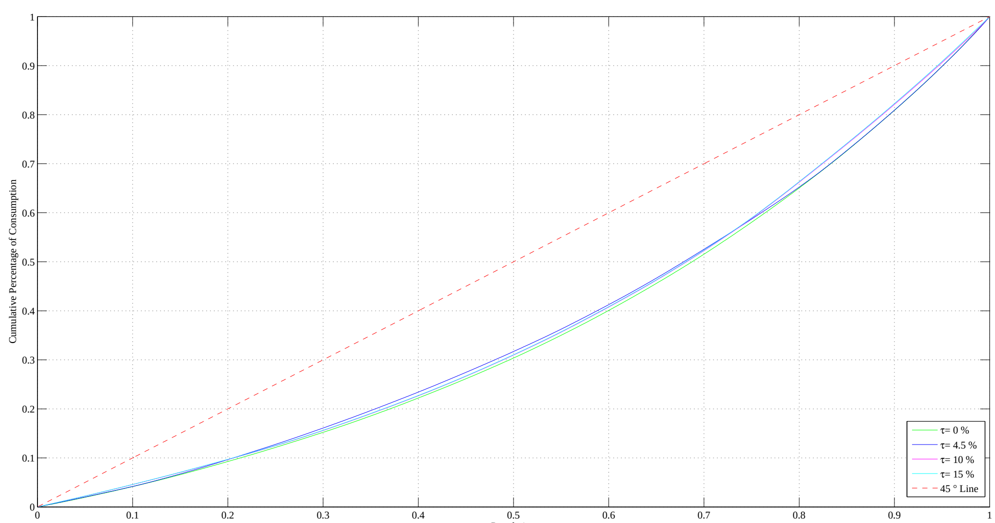
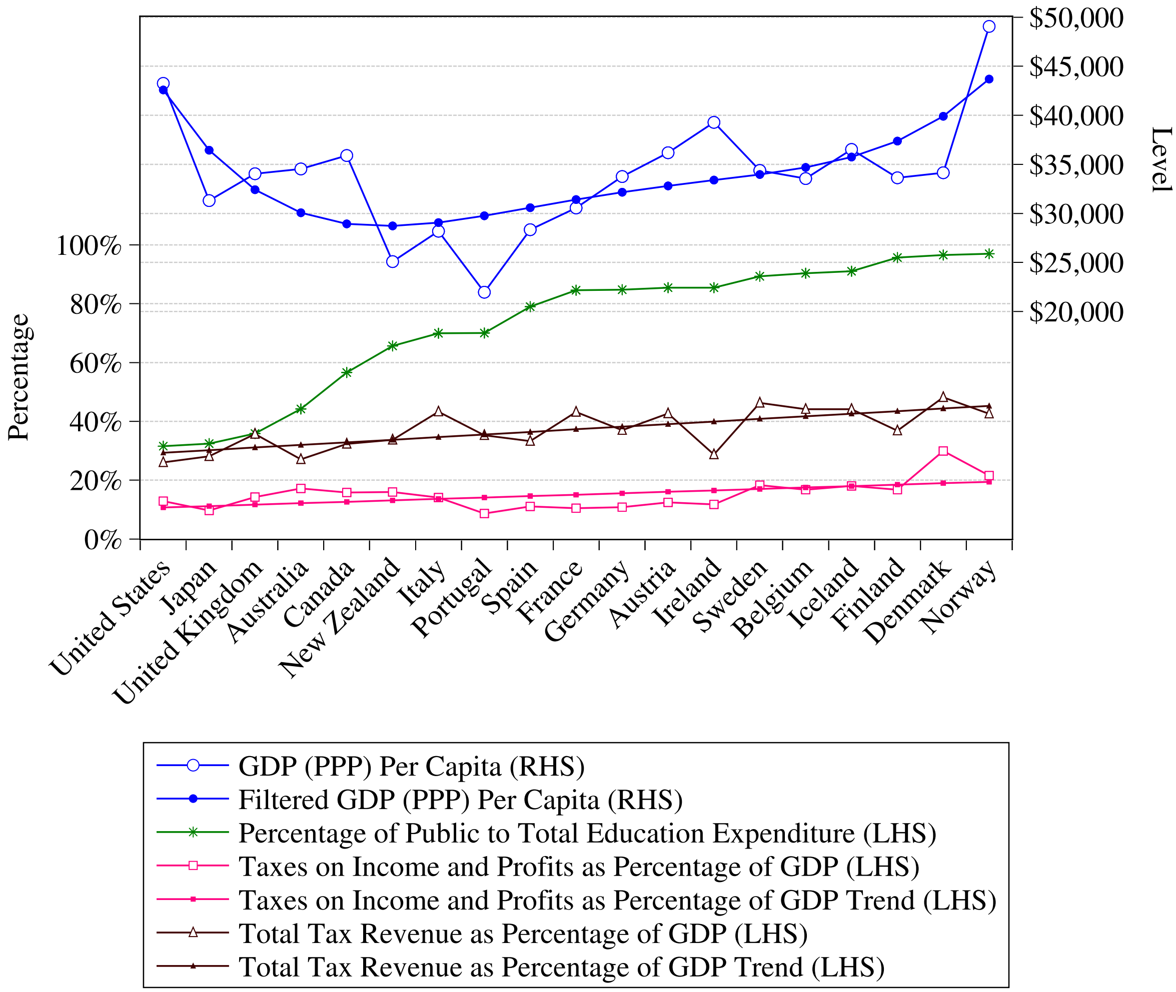


Figure 18: Lorenz Curves for of the Hybrid Model with No Public Education Spillover under Different Tax Regimes



Source: OECD Tax Revenue Database, 2008.

Figure 19: Per-Capita Output, Tax Rate and Public Education Shares of Developed Economies

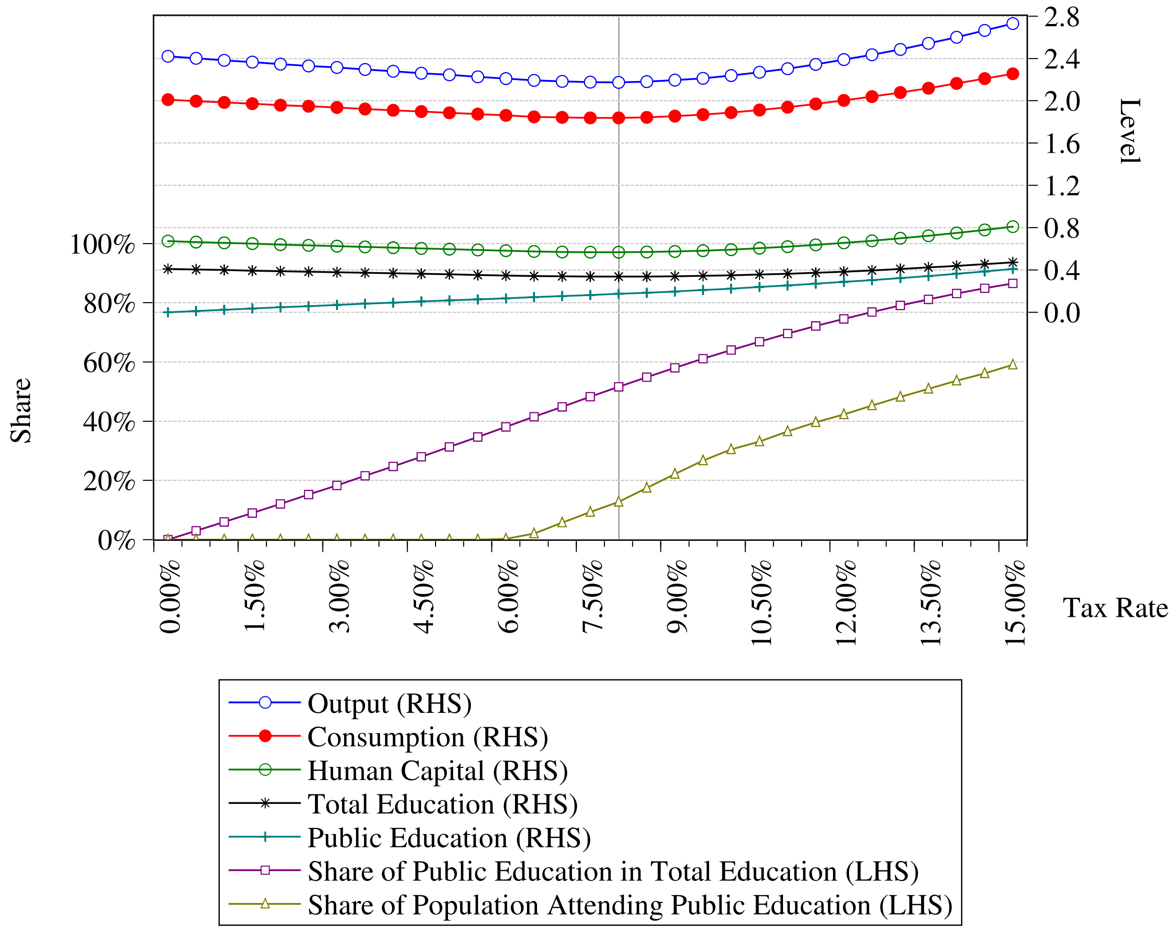


Figure 20: Stationary-Equilibria of the Hybrid Model with Maximum Public Education Spillover

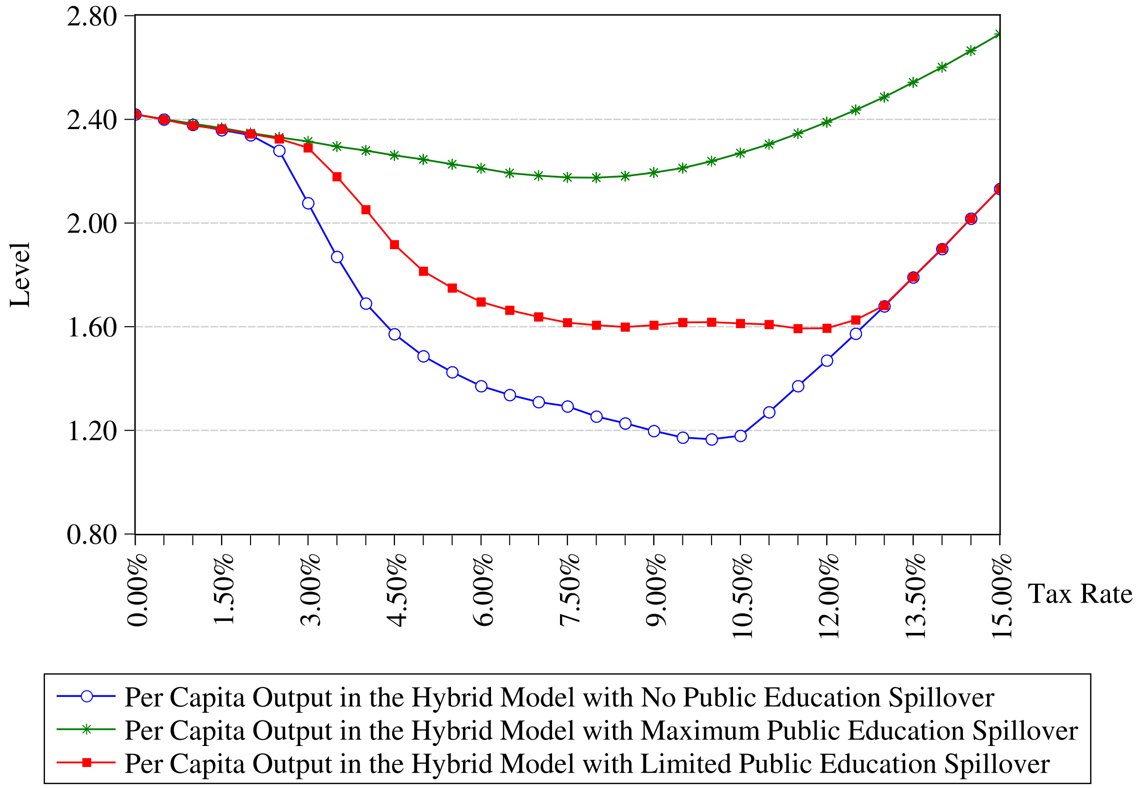


Figure 21: Per-Capita Output Comparison of the Three Hybrid Models

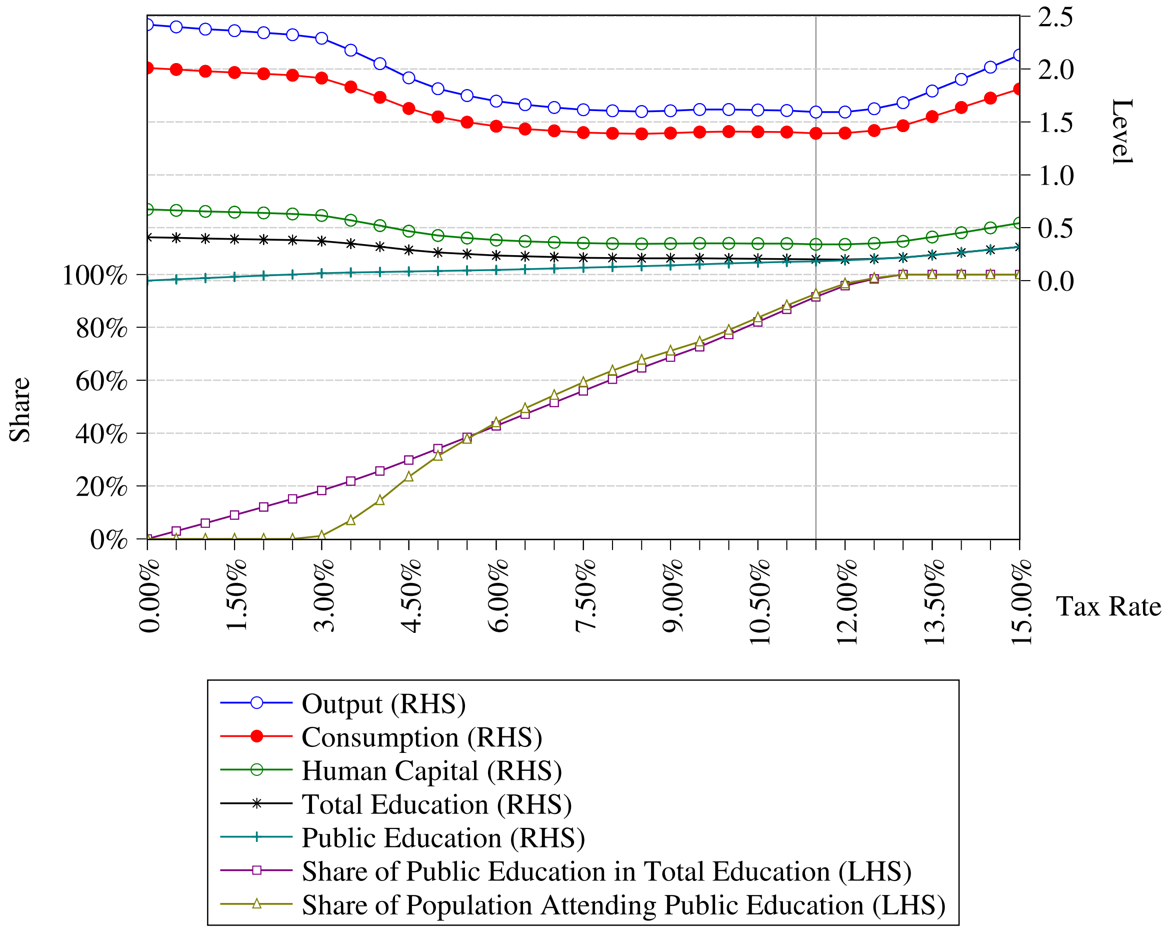
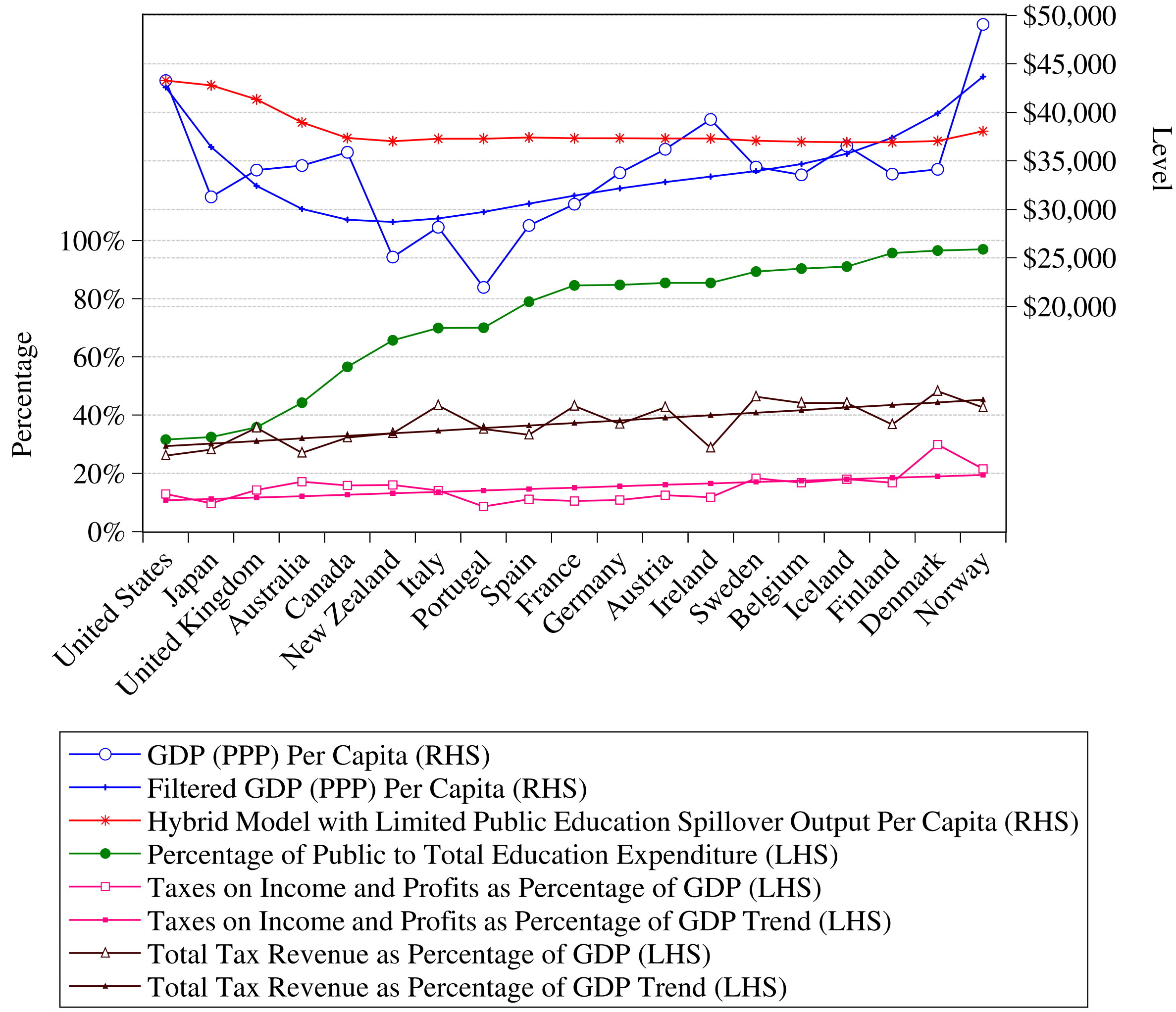


Figure 22: Stationary-Equilibria of the Hybrid Model with Limited Public Education Spillover



Source: OECD Tax Revenue Database, 2008.

Figure 23: Match of the Hybrid Model with Limited Public Education Spillover to Data

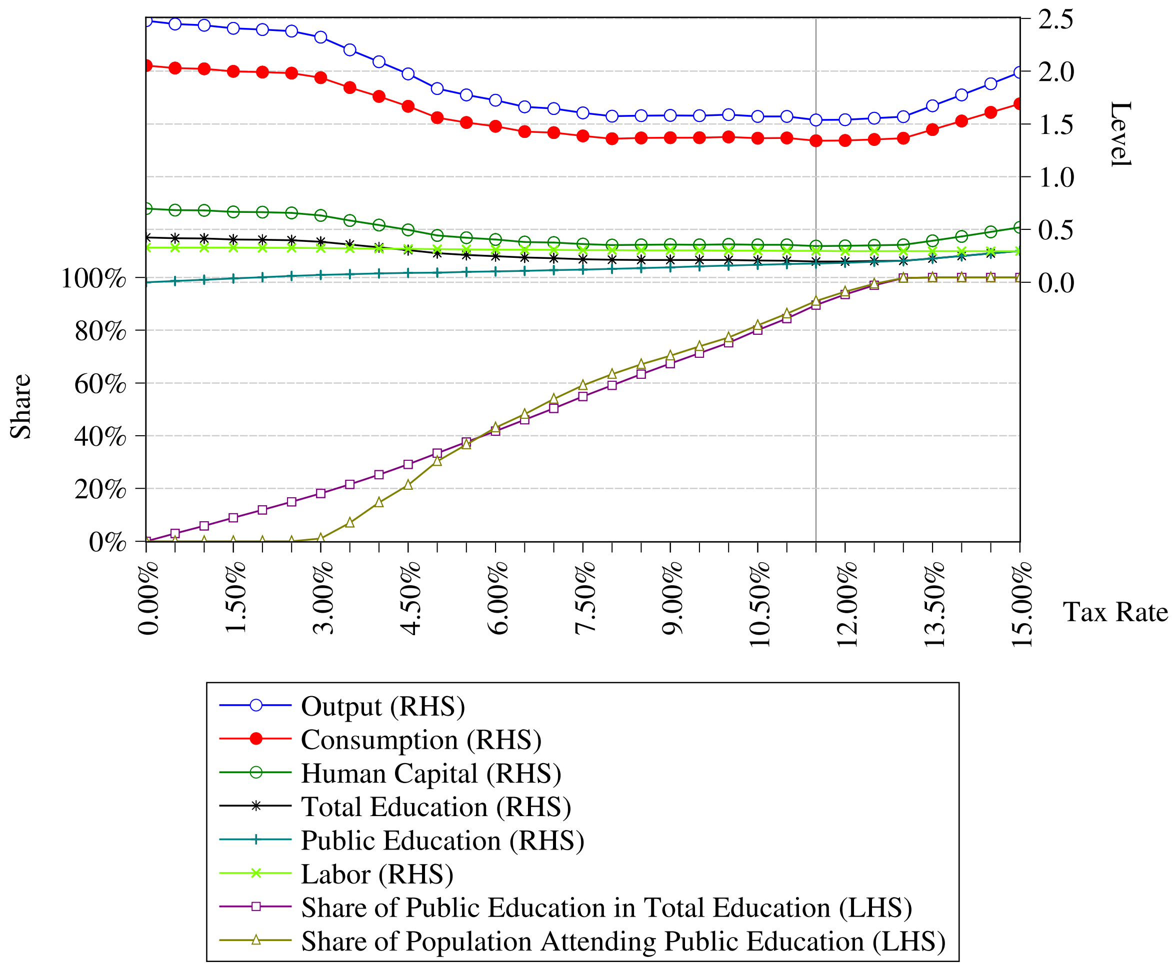


Figure 24: Stationary-Equilibria of the Hybrid Model with Limited Public Education Spillover and Endogenous Labor

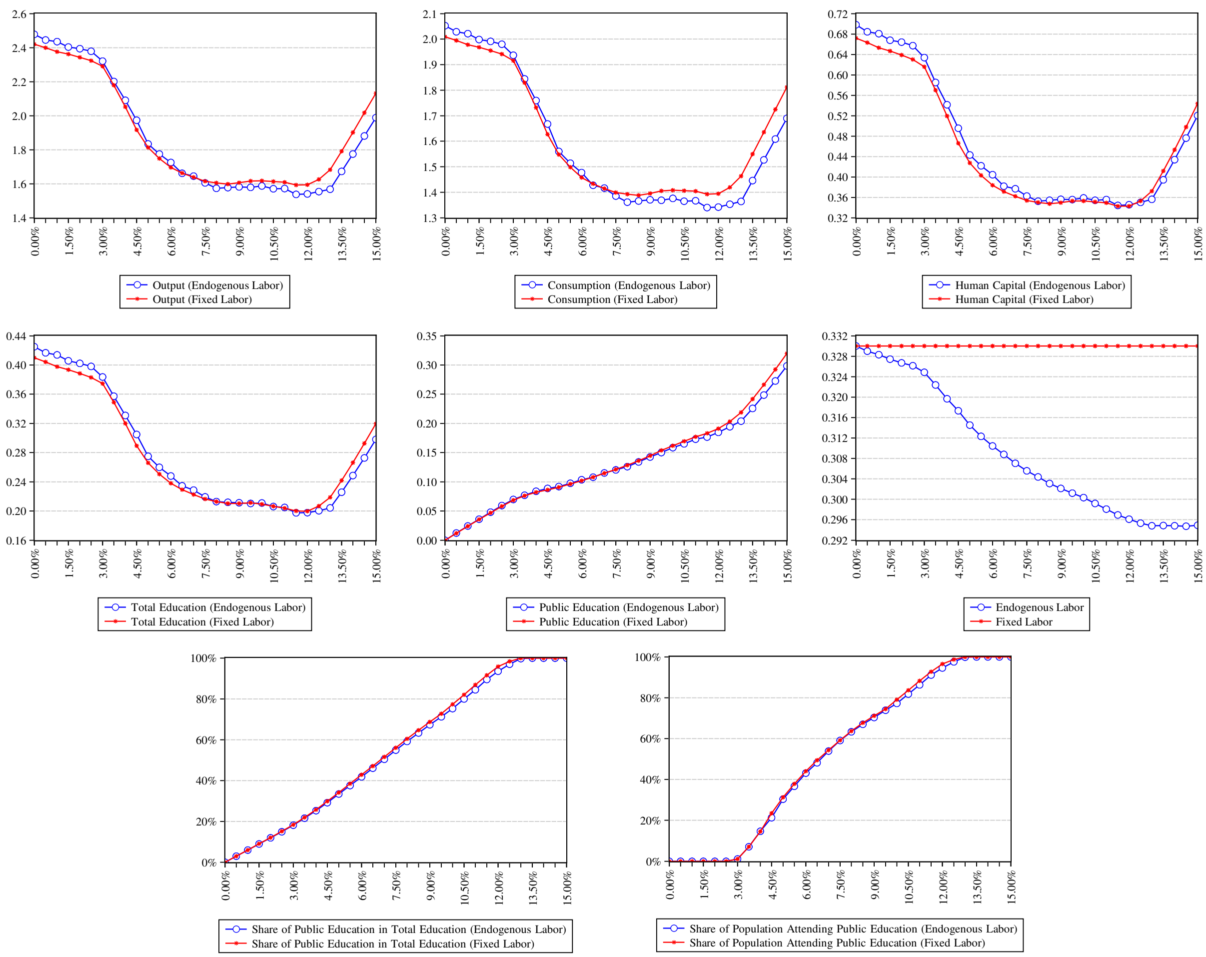


Figure 25: Comparison of the Hybrid Model with Limited Spillover (Fixed v.s. Endogenous Labor)

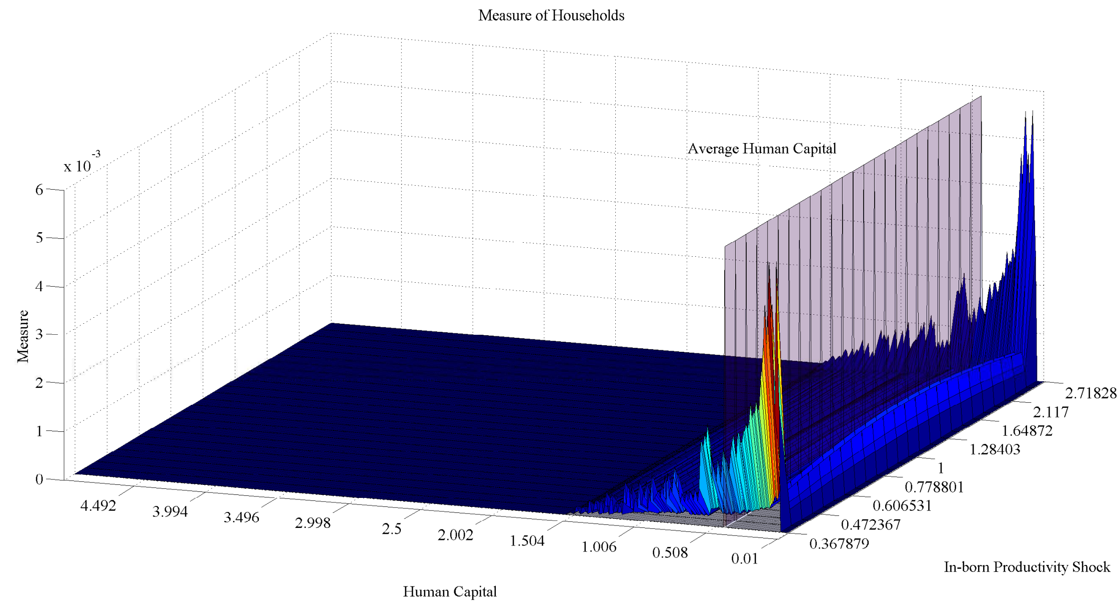


Figure 26: Distribution of Individuals over States for the Targeted U.S. Economy

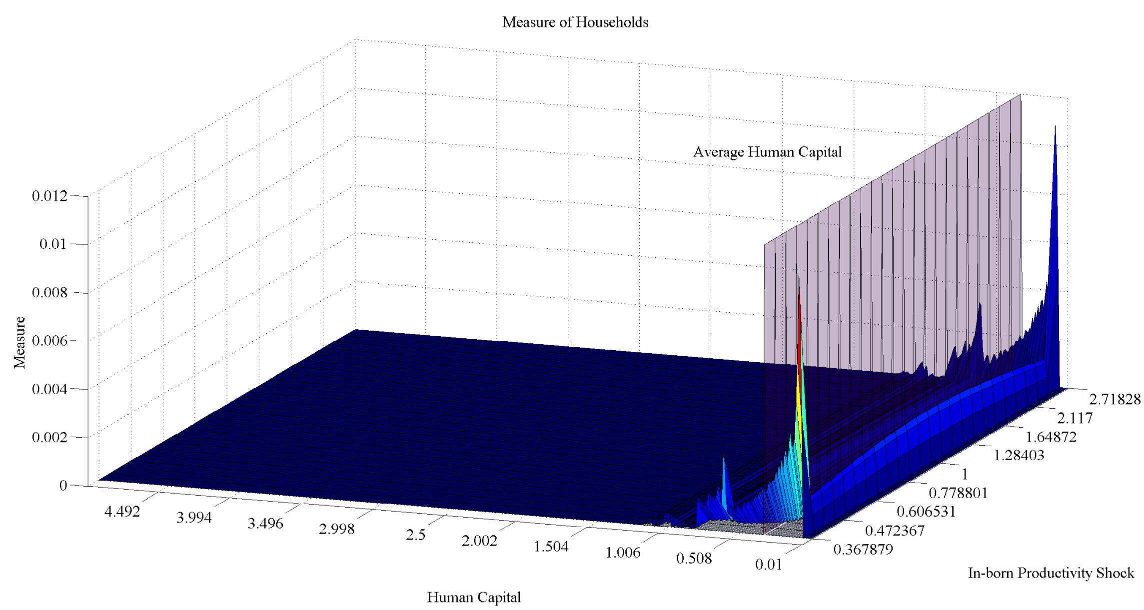


Figure 27: Distribution of Individuals over States for the Targeted Nordic Average Economy

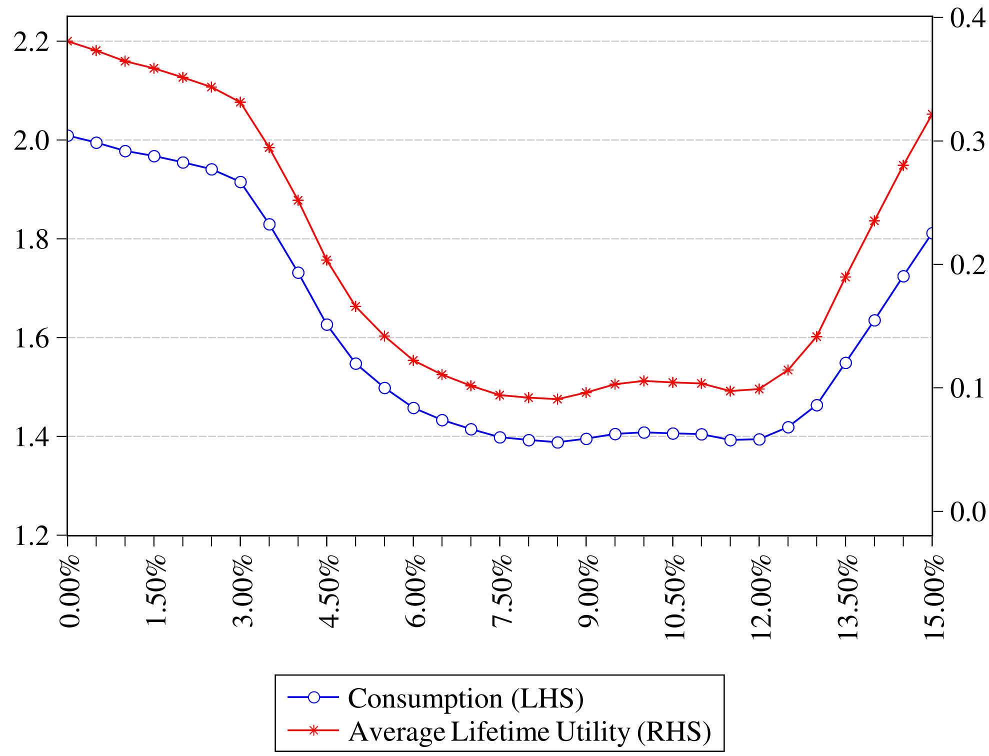


Figure 28: Average Egalitarian Welfare and Consumption

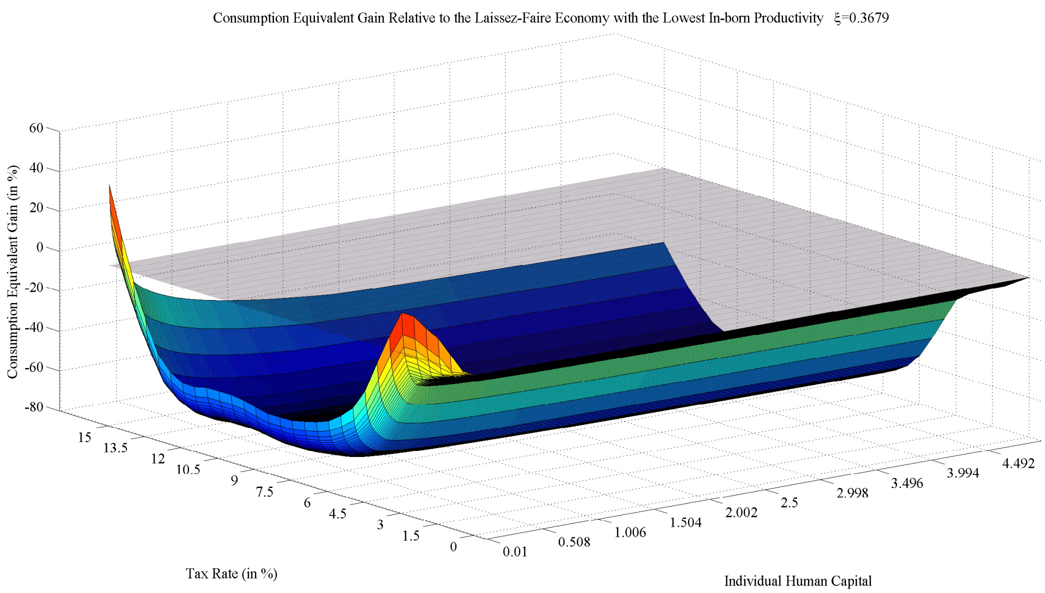


Figure 29: Consumption Equivalent Gains over Tax Rates with Lowest In-born Productivity State ($\xi = 0.3679$)

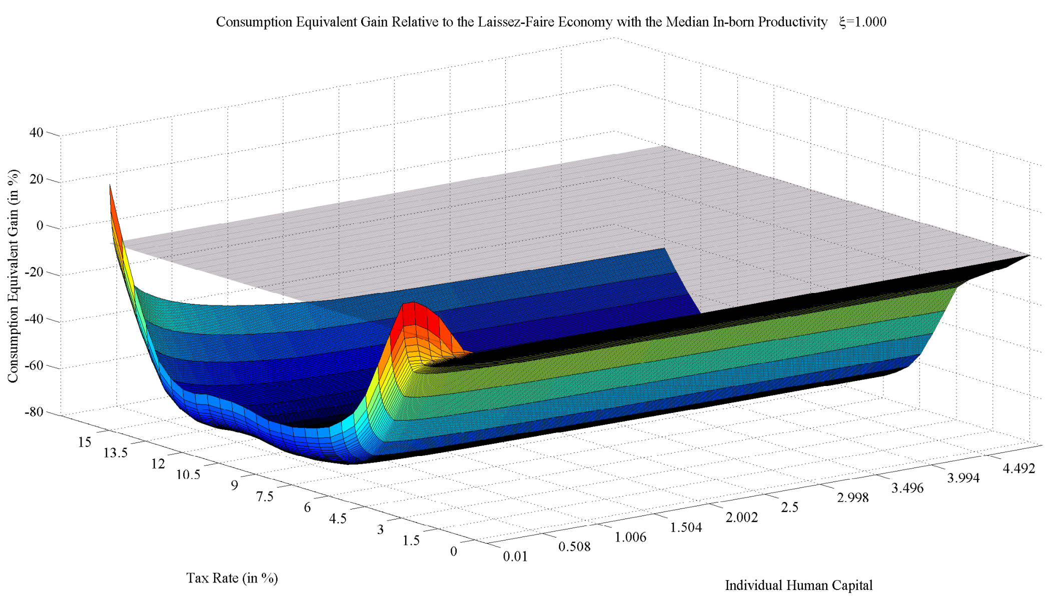


Figure 30: Consumption-Equivalent Gains over Tax Rates with Median In-born Productivity State ($\xi = 1.000$)

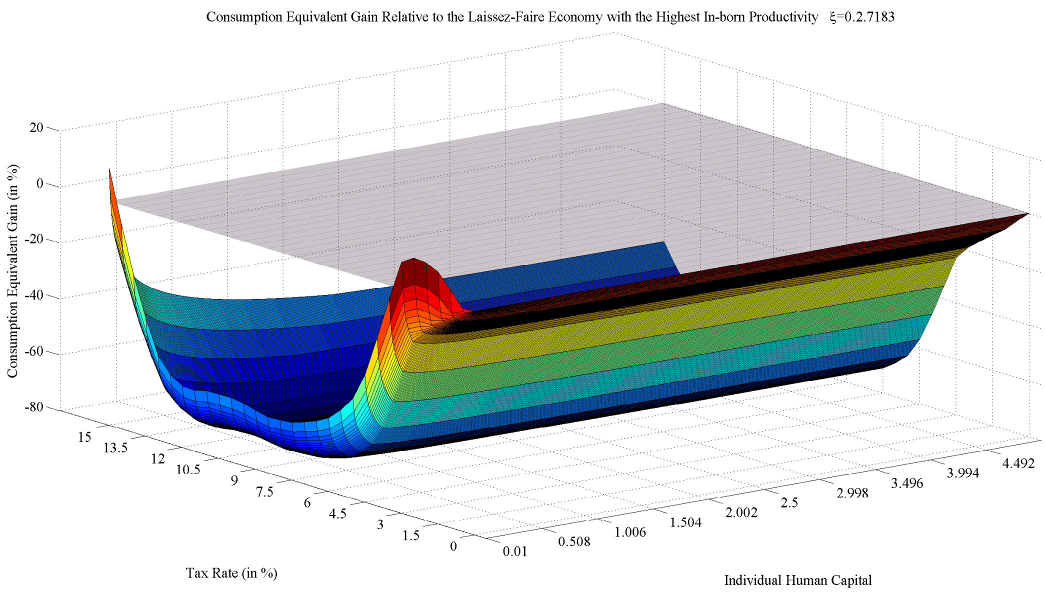


Figure 31: Consumption-Equivalent Gains over Tax Rates with Highest In-born Productivity State ($\xi = 2.7183$)

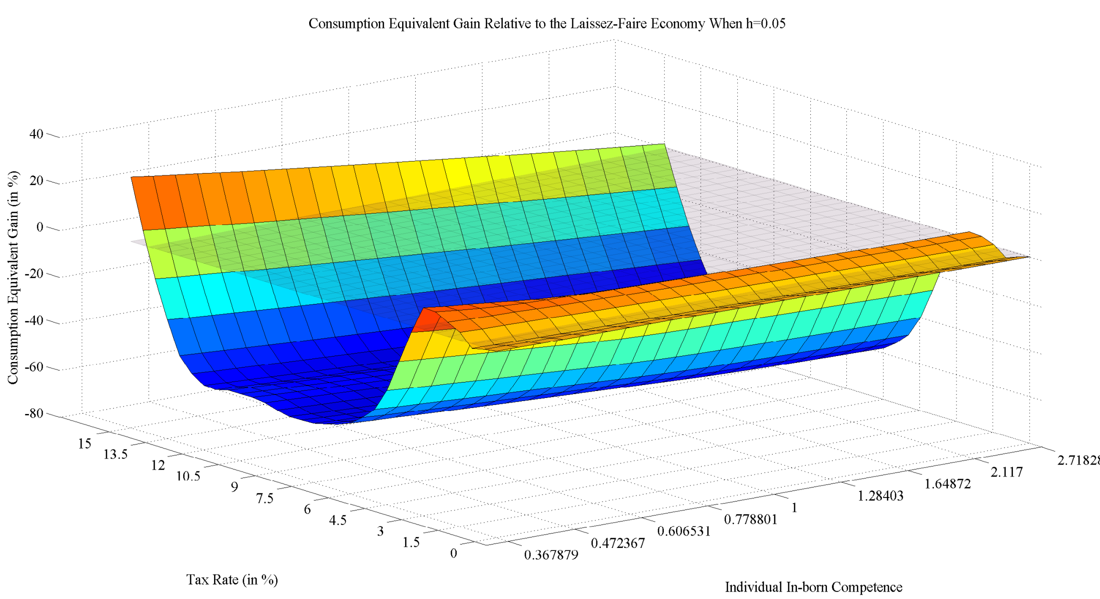


Figure 32: Consumption-Equivalent Gains over Tax Rates When $h = 0.05$

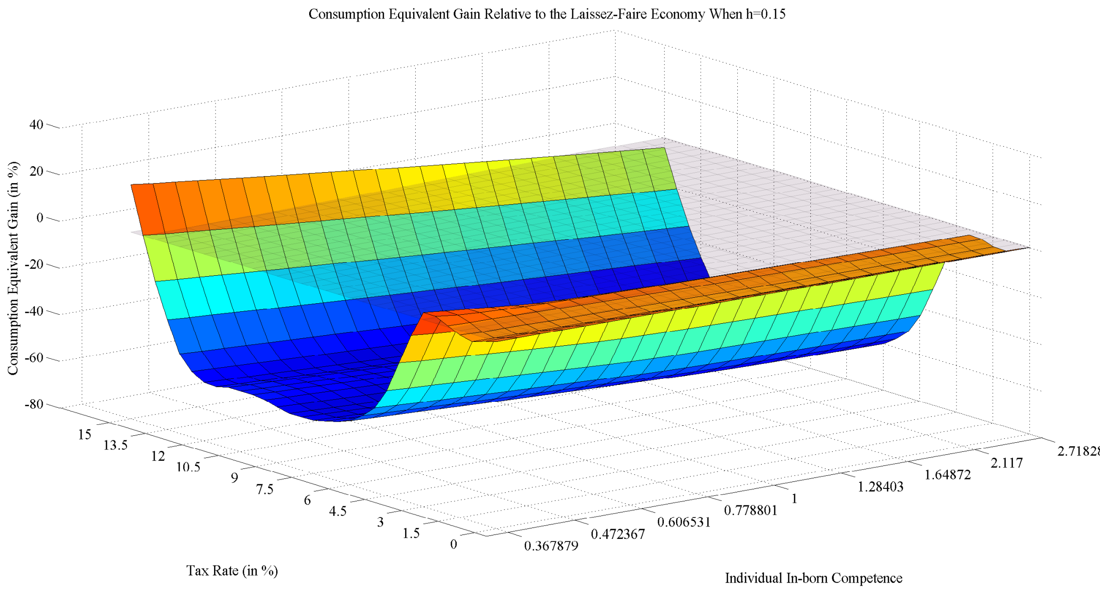


Figure 33: Consumption-Equivalent Gains over Tax Rates When $h = 0.15$

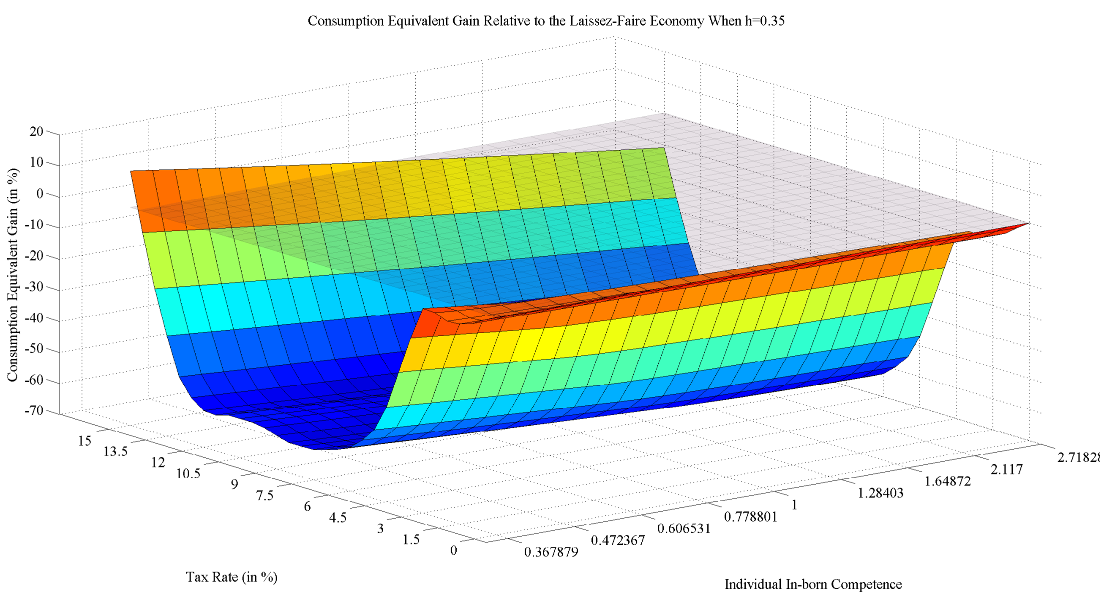


Figure 34: Consumption-Equivalent Gains over Tax Rates When $h = 0.35$

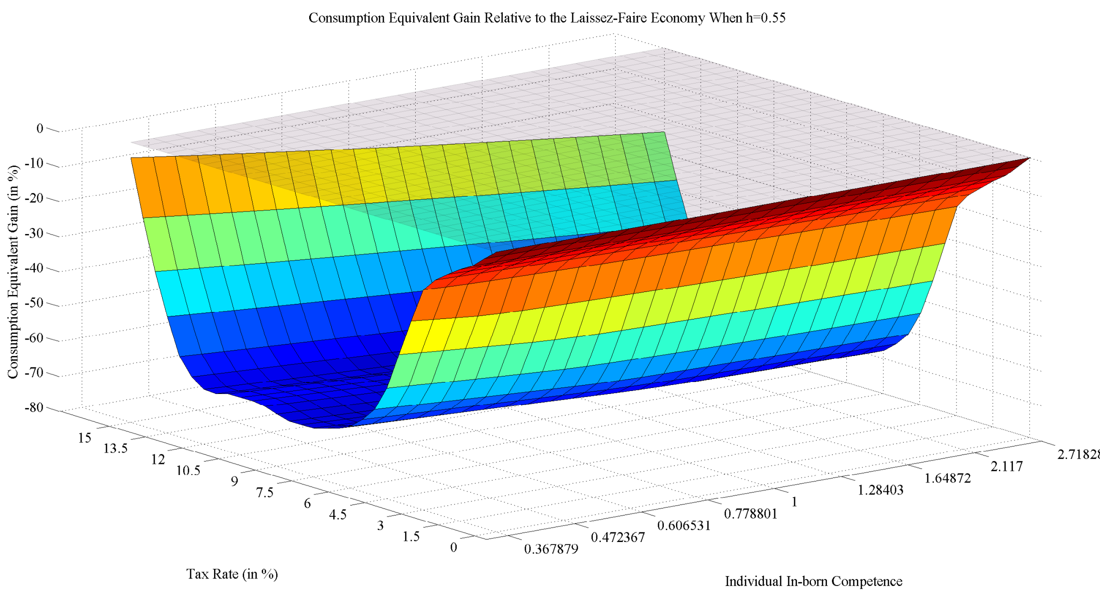


Figure 35: Consumption-Equivalent Gains over Tax Rates When $h = 0.55$

Tables

Table 1: Comparison of the Scandinavian and the U.S. Tertiary Education

	Average Public Institute Tuition[1]	Average Private Institute Tuition[1]	Average Tuition1 (Net of Subsidies)	Average Tuition/ Per-capita Income	Ratio of Students in Public Education	Net Entry Rate in Higher Education	Ratio of Population with Higher Education[2]
Denmark	$0	N/A	-$217	-0.59%	98%	57%	34%
Finland	$0	$0	-$300	-0.87%	87%	71%	37%
Iceland	$0	$4,253	$851	2.26%	80%	73%	31%
Norway	$0	$5,427	$150	0.27%	88%	70%	36%
Sweden	$0	$0	-$239	-0.63%	93%	73%	32%
Nordic Average	$0	$2,420	$49	0.09%	89%	69%	34%
USA	$5,493	$21,979	$10,412	22.42%	67%	65%	41%

1. Fees are in equivalent USD converted using PPPs.
2. Among 25-64 year-old population.
Source: Education at a Glance 2010, OECD, and World Development Indicators database, 2010.

Table 2: Comparison of the Scandinavian and the U.S. Tertiary Education Expenditures

	Higher Edu. Exp. per Student[1]	Public Exp. on Higher Edu./GDP	Private Exp. on Higher Edu./GDP	Public/ Total Exp. on Higher Edu.	Public Exp. on Higher Edu. per Student[1]	Private Exp. on Higher Edu. per Student[1]	Wages of Workers with Higher Edu.[2]
Denmark	$16,466	1.6%	0.1%	96.50%	$15,497	$969	125
Finland	$13,566	1.6%	0.1%	96.07%	$12,768	$798	148
Iceland	$6,721	1.1%	0.1%	91.01%	$6,161	$560	N/A
Norway	$17,140	1.2%	0.0%[3]	95.83%	$17,140	$614[3]	128
Sweden	$18,361	1.4%	0.2%	89.73%	$16,066	$2,295	126
Nordic Average	$14,451	1.4%	0.1%	93.83%	$13,526	$1,047	132
USA	$27,010	1.0%	2.1%	32.26%	$8,713	$18,297	177

1. Fees are in equivalent USD converted using PPPs.
2. The base salary for workers without higher education is normalized to 100 for each country.
3. Approximate values for Norway are calculated combining OECD data and Docampo (2007).
Source: Education at a Glance 2010, OECD.

Table 3: Taxes on Income and Profits as Percentage of GDP

	2005	2006	2007	2008	Average
Denmark[1]	31.16%	29.90%	29.36%	29.17%	29.90%
Finland	16.82%	16.69%	16.89%	16.82%	16.81%
Iceland	17.55%	18.28%	18.45%	17.83%	18.03%
Norway	21.43%	22.04%	21.09%	21.63%	21.55%
Sweden	19.12%	19.06%	18.35%	16.79%	18.33%
Nordic Average	21.22%	21.20%	20.83%	20.45%	20.92%
USA	12.65%	13.45%	13.61%	11.77%	12.87%

1. The total tax revenues have been reduced by the amount of any capital transfer that represents uncollected taxes. The capital transfer has been allocated.
Source: OECD Tax Database, 2010.

Table 4: Total Tax Revenue as Percentage of GDP

	2005	2006	2007	2008	Average
Denmark[1]	50.83%	49.62%	48.98%	48.18%	49.40%
Finland	43.94%	43.84%	43.00%	43.13%	43.48%
Iceland	40.65%	41.49%	40.64%	36.79%	39.89%
Norway	43.52%	43.97%	43.82%	42.60%	43.48%
Sweden	48.87%	48.32%	47.36%	46.30%	47.71%
Nordic Average	45.65%	45.45%	44.76%	43.40%	44.79%
USA	27.10%	27.85%	27.86%	26.06%	27.22%

1. The total tax revenues have been reduced by the amount of any capital transfer that represents uncollected taxes. The capital transfer has been allocated.
Source: OECD Tax Database, 2010.

Table 5: Benchmark Parameter Values

λ	Θ	γ	ρ	$\bar{l}$	ε	μ_h	σ_h	μ_ξ	σ_ξ	ν
0.625	5.000	0.200	0.800	0.330	0.300	0.000	1.000	0.000	1.000	0.500

Table 6: Benchmark Steady-State of the Hybrid Model with No Public Education Spillover

τ	$\overline{H}$	$\overline{Y}$	$\overline{C}$	$\overline{C}/\overline{Y}$	$\overline{\mathcal{E}}$	$\overline{E}$	$\overline{E}/\overline{\mathcal{E}}$	$Pop._{\overline{E}}$
0.00%	0.672	2.419	2.010	0.831	0.410	0.000	0.000%	0.000%
2.50%	0.612	2.279	1.905	0.836	0.374	0.057	15.224%	2.151%
4.50%	0.341	1.571	1.353	0.861	0.218	0.071	32.366%	39.761%
5.00%	0.312	1.486	1.287	0.866	0.199	0.074	37.253%	46.853%
7.50%	0.248	1.292	1.140	0.882	0.152	0.097	63.591%	73.419%
10.00%	0.207	1.165	1.043	0.896	0.122	0.117	95.768%	97.557%
12.50%	0.334	1.573	1.376	0.875	0.197	0.197	100.000%	100.000%
15.00%	0.544	2.132	1.813	0.850	0.320	0.320	100.000%	100.000%

Note: All variables are in per-capita terms. $\overline{H}$ denotes average human capital, $\overline{Y}$ denotes average output, $\overline{C}$ denotes average consumption,$\overline{E}$ denotes public education level, $\overline{\mathcal{E}} = \overline{E} + \int_0^1 e^i di$ denotes total expenditure on education, and $Pop._{\overline{E}}$ denotes share of population who attend public education.

Table 7: Distributional Properties of the Hybrid Model with No Public Education Spillover

τ	$GINI_h$	$GINI_y$	$GINI_c$	$GINI_e$
0.00%	0.400	0.266	0.265	0.264
2.50%	0.402	0.267	0.258	0.273
4.50%	0.422	0.281	0.253	0.368
5.00%	0.421	0.281	0.251	0.372
7.50%	0.409	0.270	0.246	0.286
10.00%	0.387	0.257	0.253	0.041
12.50%	0.379	0.252	0.252	0.000
15.00%	0.379	0.252	0.252	0.000

Table 8: Steady-State with No Idiosyncratic Shocks ($\sigma_\xi^2 = 0$)

τ	$\overline{H}$	$\overline{Y}$	$\overline{C}$	$\overline{C}/\overline{Y}$	$\overline{\mathcal{E}}$	$\overline{E}$	$\overline{E}/\overline{\mathcal{E}}$	$\%Pop._{\overline{E}}$
0.00%	0.140	0.967	0.797	0.824	0.170	0.000	0.00%	0.00%
4.50%	0.168	0.862	0.724	0.839	0.138	0.039	28.04%	0.00%
10.00%	0.035	0.386	0.348	0.900	0.039	0.039	100.00%	100.00%
15.00%	0.094	0.751	0.638	0.850	0.113	0.113	100.00%	100.00%

Note: The results presented in this table, as well as Table 9-15 are of the hybrid model with no public education spillover. Qualitatively similar results are obtained for the other two hybrid model specifications.

Table 9: Steady-State with High Return of Education ($\varepsilon = 0.60$)

τ	$\overline{H}$	$\overline{Y}$	$\overline{C}$	$\overline{C}/\overline{Y}$	$\overline{\mathcal{E}}$	$\overline{E}$	$\overline{E}/\overline{\mathcal{E}}$	$\%Pop._{\overline{E}}$
0.00%	1.686	4.298	3.019	0.702	1.279	0.000	0.00%	0.00%
4.50%	1.565	4.077	2.906	0.713	1.171	0.183	15.67%	4.77%
10.00%	0.841	2.702	2.086	0.772	0.617	0.270	43.83%	57.05%
15.00%	0.581	2.179	1.770	0.812	0.409	0.327	79.86%	88.70%

Table 10: Steady-State with No Complementarities ($\gamma = 0$)

τ	$\overline{H}$	$\overline{Y}$	$\overline{C}$	$\overline{C}/\overline{Y}$	$\overline{\mathcal{E}}$	$\overline{E}$	$\overline{E}/\overline{\mathcal{E}}$	$\%Pop._{\overline{E}}$
0.00%	0.431	1.646	1.111	0.675	0.535	0.000	0.00%	0.00%
4.50%	0.379	1.494	1.049	0.703	0.444	0.067	15.13%	25.08%
10.00%	0.245	1.111	0.827	0.744	0.285	0.111	39.06%	63.39%
15.00%	0.179	0.929	0.711	0.766	0.218	0.139	64.01%	83.71%

Table 11: Steady-State with No Intergenerational Skill Transmission ($\gamma = 1$)

τ	$\overline{H}$	$\overline{Y}$	$\overline{C}$	$\overline{C}/\overline{Y}$	$\overline{\mathcal{E}}$	$\overline{E}$	$\overline{E}/\overline{\mathcal{E}}$	$\%Pop._{\overline{E}}$
0.00%	0.971	3.060	2.600	0.850	0.460	0.000	0.00%	0.00%
4.50%	0.444	1.867	1.644	0.881	0.223	0.084	37.72%	46.98%
10.00%	0.398	1.757	1.582	0.900	0.176	0.176	100.00%	100.00%
15.00%	1.172	3.449	2.932	0.850	0.517	0.517	100.00%	100.00%

Table 12: Steady-State with Lower Labor Supply ($\bar{l} = 0.25$)

τ	$\overline{H}$	$\overline{Y}$	$\overline{C}$	$\overline{C}/\overline{Y}$	$\overline{\mathcal{E}}$	$\overline{E}$	$\overline{E}/\overline{\mathcal{E}}$	$\%Pop._{\overline{E}}$
0.00%	0.588	2.005	1.665	0.831	0.340	0.000	0.000%	0.000%
4.50%	0.296	1.295	1.116	0.861	0.180	0.058	32.421%	40.070%
10.00%	0.180	0.962	0.862	0.896	0.100	0.096	96.202%	97.890%
15.00%	0.475	1.765	1.501	0.850	0.265	0.265	100.000%	100.000%

Table 13: Steady-State with Persistent In-born Productivity Shocks ($\kappa = 0.40$)

τ	$\overline{H}$	$\overline{Y}$	$\overline{C}$	$\overline{C}/\overline{Y}$	$\overline{\mathcal{E}}$	$\overline{E}$	$\overline{E}/\overline{\mathcal{E}}$	$\%Pop._{\overline{E}}$
0.00%	0.078	0.606	0.501	0.826	0.106	0.000	0.000%	0.000%
4.50%	0.062	0.526	0.451	0.858	0.074	0.024	31.772%	41.629%
10.00%	0.048	0.450	0.393	0.873	0.057	0.045	78.627%	86.932%
15.00%	0.059	0.513	0.436	0.850	0.077	0.077	99.900%	99.883%

Table 14: Steady-State with Hybrid Model with Maximum Public Education Spillover

τ	$\overline{H}$	$\overline{Y}$	$\overline{C}$	$\overline{C}/\overline{Y}$	$\overline{\mathcal{E}}$	$\overline{E}$	$\overline{E}/\overline{\mathcal{E}}$	$Pop._{\overline{E}}$
0.00%	0.672	2.419	2.010	0.831	0.410	0.000	0.00%	0.00%
2.50%	0.633	2.330	1.947	0.836	0.383	0.058	15.20%	0.00%
4.50%	0.604	2.261	1.898	0.839	0.363	0.102	28.02%	0.00%
5.00%	0.597	2.245	1.887	0.840	0.358	0.112	31.32%	0.00%
7.50%	0.567	2.175	1.837	0.845	0.338	0.163	48.26%	9.28%
10.00%	0.593	2.238	1.889	0.844	0.349	0.224	64.06%	30.43%
12.50%	0.677	2.436	2.040	0.837	0.396	0.304	76.89%	45.31%
15.00%	0.810	2.729	2.256	0.827	0.473	0.409	86.56%	59.09%

Table 15: Distributional Properties of the Hybrid Model with Maximum Public Education Spillover

τ	$GINI_h$	$GINI_y$	$GINI_c$	$GINI_e$
0.00%	0.400	0.265	0.266	0.264
2.50%	0.401	0.266	0.259	0.261
4.50%	0.401	0.267	0.254	0.258
5.00%	0.401	0.267	0.253	0.257
7.50%	0.401	0.267	0.246	0.249
10.00%	0.398	0.264	0.243	0.210
12.50%	0.392	0.260	0.242	0.155
15.00%	0.387	0.257	0.243	0.100

Table 16: Steady-State of the Hybrid Model with Limited Public Education Spillover

τ	$\overline{H}$	$\overline{Y}$	$\overline{C}$	$\overline{C}/\overline{Y}$	$\overline{\mathcal{E}}$	$\overline{E}$	$\overline{E}/\overline{\mathcal{E}}$	$Pop._{\overline{E}}$
0.00%	0.672	2.419	2.010	0.831	0.410	0.000	0.00%	0.00%
2.50%	0.630	2.324	1.941	0.835	0.383	0.058	15.17%	0.00%
4.78%	0.441	1.851	1.577	0.852	0.275	0.089	32.27%	28.34%
5.00%	0.427	1.814	1.548	0.853	0.266	0.091	34.12%	31.34%
7.50%	0.354	1.615	1.398	0.866	0.216	0.121	55.99%	59.22%
10.00%	0.353	1.618	1.408	0.871	0.209	0.162	77.25%	78.99%
11.77%	0.343	1.593	1.393	0.875	0.200	0.188	93.83%	94.63%
12.50%	0.353	1.625	1.419	0.873	0.207	0.203	98.34%	98.64%
15.00%	0.544	2.131	1.812	0.850	0.320	0.320	100.00%	100.00%

Table 17: Distributional Properties of the Hybrid Model with Limited Public Education Spillover

τ	$GINI_h$	$GINI_y$	$GINI_c$	$GINI_e$
0.00%	0.400	0.265	0.266	0.264
2.50%	0.400	0.266	0.262	0.263
4.78%	0.414	0.276	0.251	0.330
5.00%	0.414	0.276	0.249	0.332
7.50%	0.410	0.272	0.239	0.298
10.00%	0.400	0.264	0.239	0.194
11.77%	0.389	0.258	0.249	0.063
12.50%	0.382	0.253	0.251	0.017
15.00%	0.379	0.252	0.252	0.000

Table 18: Comparison of the Model to the Data

	Country	$\overline{E}/\overline{\mathcal{E}}$	τ	Y/Y^{US}	$\overline{E}/\overline{E}^{US}$	$\mathcal{E}/Y$	$Pop._{\overline{E}}$	$GINI_e$
Model	U.S.	32.27%	4.78%	100%	100%	14.83%	28%	0.33
	Nordic Aver.	93.90%	11.77%	86%	211%	12.54%	95%	0.06
Data	U.S.	32.26%	12.87%	100%	100%	3.10%	67%	N/A (+)
	Nordic Aver.	93.90%	20.92%	87%	155%	1.60%	89%	N/A (−)

Note: Y denotes output per capita, $\overline{E}$ denotes public education expenditure, $\overline{\mathcal{E}}$ denotes total expenditure on education, τ denotes taxes on income and profits as a percentage of GDP, and $Pop._{\overline{E}}$ denotes share of population who attend public education.

Table 19: Steady-State of the Hybrid Model with Endogenous Labor

τ	$\overline{H}$	$\overline{Y}$	$\overline{C}$	$\overline{C}/\overline{Y}$	$\overline{L}$	$\overline{\mathcal{E}}$	$\overline{E}$	$\overline{E}/\overline{\mathcal{E}}$	$Pop._{\overline{E}}$
0.00%	0.698	2.477	2.052	0.828	0.330	0.425	0.000	0.00%	0.00%
2.50%	0.657	2.378	1.980	0.833	0.326	0.398	0.059	14.94%	0.00%
4.89%	0.458	1.871	1.590	0.850	0.315	0.281	0.091	32.26%	29.08%
5.00%	0.443	1.834	1.559	0.850	0.315	0.275	0.092	33.36%	30.33%
7.50%	0.363	1.604	1.385	0.863	0.306	0.219	0.120	54.87%	59.05%
10.00%	0.359	1.587	1.376	0.867	0.300	0.211	0.159	75.25%	77.21%
12.02%	0.346	1.544	1.345	0.871	0.296	0.199	0.187	93.83%	94.90%
12.50%	0.350	1.553	1.353	0.871	0.295	0.200	0.194	96.95%	97.53%
15.00%	0.520	1.988	1.690	0.850	0.295	0.298	0.298	100.00%	100.00%

Table 20: Distributional Properties of the Hybrid Model with Endogenous Labor

τ	$GINI_h$	$GINI_y$	$GINI_c$	$GINI_e$	$GINI_l$
0.00%	0.400	0.265	0.267	0.260	0.002
2.50%	0.400	0.266	0.268	0.256	0.003
4.89%	0.415	0.283	0.257	0.330	0.023
5.00%	0.414	0.282	0.256	0.330	0.023
7.50%	0.410	0.280	0.240	0.303	0.024
10.00%	0.400	0.271	0.237	0.204	0.017
12.02%	0.390	0.261	0.249	0.068	0.006
12.50%	0.385	0.256	0.251	0.027	0.003
15.00%	0.379	0.252	0.252	0.000	0.001

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Appendix

Computational Strategy

The computational strategy I employ is a modified heterogeneous-agent economy with incomplete markets algorithm *à la* Huggett (1993). The algorithm works as follows: First I make initial guesses for aggregate human capital $\overline{H}$ and public education $\overline{E}$ at the same time. Second, taking these values given, I solve for the optimal decision rules of agents in all possible idiosyncratic human capital h and in-born cognitive competence ξ state pairs by value function iteration. Third, I perform Monte Carlo simulations for sufficiently large number of periods and households (11000 periods and 1000 households), discard some initial number of periods (1000 periods), and using the generated data, I calculate the mean of the generated aggregate human capital and public education levels, i.e. $\sum_{t=1}^{T} \frac{H_t^{sim}}{T} = \overline{\widehat{H}}$ and $\sum_{t=1}^{T} \frac{E_t^{sim}}{T} = \overline{\widehat{E}}$. If the mean of simulated values for aggregate human capital or public education are different than initial guesses for the variables at a reasonable tolerance level, i.e. if $|\overline{\widehat{H}} - \overline{H}| > \epsilon^{tol}$ or $|\overline{\widehat{E}} - \overline{E}| > \epsilon^{tol}$, I update initial guesses and go over the same steps until convergence is achieved. For robustness check, I also derive the stationary distribution of the population using the decision rules and the exogenous law of motion for the in-born productivity shocks, and using the stationary distribution, I calculate the implied aggregate human capital and public education, and compare them against the simulated values and initial guesses. I verify that the implied human capital and public education values are the same convergent values derived through the Monte Carlo simulations. At the same time, I also ensure that the grids are fine enough so that computational errors are kept at a minimal level. For each tax rate I go over the same steps and derive the respective stationary equilibrium.